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OIL SPILL RESPONSE SCENARIOS FOR REMOTE ARCTIC ENVIRONMENTS

by

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16. ABSTRACT

Special problems occur during oil spill cleanup in remote inland areas in cold climates. In Alaska these problems result from the harsh climate, the unusual terrain features, and the special problems of spills along swift rivers.

The analysis begins with a description of the environmental conditions that occur in Alaska that affect oil spill behavior and oil spill cleanup. The study then describes four spill scenarios in remote areas giving engineering details of the mechanics of the spill movement and the cleanup effort. One scenario covers a winter blowout of a well on the north slope tundra. The next involves a Trans-Alaska Pipeline spill in an area where the pipeline passes under a sensitive mountain stream. The third scenario covers a fuel farm spill at an inland Alaskan village that contaminates the local water supply. The fourth scenario involves a fuel tank truck spill into a sensitive sport fishing stream. The study describes the impact of these spills on the environment and the circumstances that dictate a particular spill response method. Further, it provides a numerical evaluation of the effectiveness of the spill response effort and the cost effectiveness of three incremental levels of spill response for the cleanup effort.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

Special problems occur during oil spill cleanup in remote inland areas in cold climates. In Alaska these problems result from the harsh climate, the unusual terrain features, and the special problems of spills along swift rivers. This report describes the environmental conditions that occur in Alaska, the way that these conditions affect spill situations in remote areas, and the spill response procedures that can be used to deal with these situations. The report evaluates the effectiveness of three levels of spill response for each spill situation and proposes a set of research and development initiatives that would improve response effectiveness in these situations.

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Director
Municipal Environmental Research
Laboratory

ABSTRACT

The U.S. Environmental Protection Agency has recognized that special problems occur during oil spill cleanups in remote inland areas with cold climates. In Alaska, these problems result from the harsh arctic and subarctic climate, the unusual terrain features, and the special problems of spills along swift rivers. The purpose of this study is to describe and analyze these problems using four typical oil spill scenarios.

The study begins by describing the environmental conditions that occur in Alaska that affect oil spill behavior and oil spill cleanup. This description emphasizes those aspects of the environment that have the greatest impact on spill behavior and cleanup.

The study then describes four spill scenarios in remote areas giving engineering details of the mechanics of the spill movement and the mechanics of the cleanup effort. One scenario covers a winter blowout of an exploration well on the north slope tundra. The next involves a Trans-Alaska Pipeline spill on the Brooks Range in an area where the pipeline passes under a sensitive mountain stream. The third scenario covers a fuel farm spill at an inland Alaskan village that contaminates the local water supply. The fourth scenario involves a fuel tank truck spill into a sensitive sport fishing stream.

The study describes the impact of these spills on the environment and the circumstances that dictate a particular spill response method. Further, it provides a numerical evaluation of the effectiveness of the spill response effort and the cost effectiveness of three incremental levels of spill response for the cleanup effort.

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SYMBOLS

A -- plan area of oil
$\vec{C}_c$ -- current velocity vector perpendicular to wind (cross-wind)
$\vec{C}_p$ -- current velocity vector parallel to wind
d -- depth to groundwater
D -- maximum depth of penetration
$\vec{D}$ -- drift velocity vector
g -- gravity constant
H -- thickness of oil in capillary zone
ℓ -- one-dimensional length
K -- infiltration constant
n -- Manning number
Q -- oil discharge rate
R -- radius of spreading
R_e -- Reynolds number
S -- maximum spread area
t -- time
U_s -- slick speed
U_w -- current speed
$\overline{u}$ -- slick velocity vector
$\vec{U}_{10}$ -- wind velocity vector
$\vec{U}_{10}$ -- wind speed at 10 m height
U -- mean slick velocity
V -- volume of oil
w -- width of slick
α -- contact angle
∞ -- ground slope angle
Δ -- density difference $\rho_w - \rho_o/\rho_w$
δ -- slick thickness
η -- roughness height
ν_o -- kinetic viscosity of oil
ρ_o -- density of oil
ρ_w -- density of water
σ -- net surface tension = $\sigma_o (1 - \cos\propto)$
σ_o -- interfacial energy

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SECTION 1

INTRODUCTION

OBJECTIVE

A review of the U.S. Environmental Protection Agency's cold climate oil spill response capability indicated that a need existed to assess spill control and response procedures in a variety of cold weather conditions. Particularly, an assessment was required to address operational programs with an emphasis on logistics and practical solutions to the real world problems.

The format for conducting this investigation was determined to be a series of oil spill response scenarios for remote arctic environments focusing on the operational constraints of moving personnel and equipment to the site of a remote inland spill, performing cleanup operations at the spill site, and safely demobilizing personnel and equipment at the completion of the spill response effort. The spill scenarios would be developed in a way that would permit operating industries to prepare and update contingency plans using the best available information on the capability of current spill response equipment. In addition, Federal and State agencies would be able to use the results of the project for more effective regulation of the spill response efforts of the petroleum industry in Alaska.

Since it was determined that the technical analysis of the study was to be based on a series of spill scenarios, these scenarios had to be selected with great care. The spill scenarios were to represent a number of distinct, but typical, remote inland Alaskan environments. To select the kinds of environments to be analyzed, it was necessary to characterize the kinds of environments that occur in Alaska and classify them according to type. It was determined that the description of the area associated with each scenario should include the topography, climate, population, social, environmental, and economic conditions that affect spill response in that area. In addition, it was determined that an assessment should be made of any conditions that would affect the type of oil spill response to be considered, including logistics, housing, personnel, safety, comfort, mobility, equipment maintenance and operation requirements, and transportation. To completely characterize the spill situation, the area description would also include the types of oil spilled, spill volume, oil movement, and the impact of these spills on local social, economic, and environmental structures.

Describing the spill situation is important in determining spill behavior and spill impact; however, this information is only background for the analysis to determine how the spill could be recovered most effectively. This analysis was to begin by developing criteria to be used for selecting spill response equipment for each spill scenario. The criteria developed would include the volume of each spill, the efficiency of various pieces of response equipment, maintenance and operating requirements for that equipment, and the effects of cold, snow, ice, wind, and darkness on spill cleanup effectiveness. The equipment reviewed for use in the scenarios would include conventional spill response equipment plus other types of construction equipment that are often employed in inland spill response situations.

Criteria for evaluating spill response equipment were developed to select the equipment needed for an effective spill response procedure or method. The spill response methods for each response scenario were then to be described in detail so that the effectiveness of each method could be determined. The description of the spill response methods was also to include the potential impact the procedure may have on social, economic, and environmental institutions. All possible methods of spill response were to be considered including the alternative of no response.

Finally, the costs of the spill response effort were to be determined including the costs of hardware, labor, stockpiling equipment, equipment maintenance, and operation. These costs would finally be combined in a cost/effectiveness analysis.

DEVELOPMENT OF STUDY ANALYSIS

The detailed requirements described in the objectives of the study were met through a set of systematic project steps. These steps are described in the paragraphs that follow.

Alaskan Profiles

The scenarios for this analysis were to be selected to illustrate spill response conditions in four typical remote Alaskan environments. The Alaskan Profiles were therefore developed to characterize the types of environmental and social conditions that occur in Alaska and the kinds of problems that would develop as a result of spills in these areas.

The information developed in the profiles falls into two broad categories; the natural environment and the human environment. For the purposes of studying the effects of oil spills, the natural environment includes:

- Climate
- Topography
- Geology
- Ecology.

Those aspects of the human environment that are related to oil spill problems include:

- Population and society
- The economy
- Transportation systems
- Petroleum development.

Alaskan Inland Oil Spill Behavior

To determine the impact of the spilled oil on the environment and the way in which the spill can be most effectively recovered, it is necessary to describe the way in which the spilled oil will move in the environment. This section therefore develops quantitative relationships that show how spilled oil behaves in remote Alaskan environments. Specifically, it describes the movement of oil spilled on:

- Open water
- Frozen ground and ice
- Snow
- Water during freezeup
- Water under ice
- Water at breakup of the ice cover
- Gravel
- Soil
- Ground water.

Evaporation of spilled oil is one of the most important characteristics in determining how much oil will be available for recovery, and the condition of the oil at the time of recovery. This section therefore also describes spill evaporation characteristics for a wide range of spill environments.

Oil Spill Scenario Selection

The spill scenarios were selected to fulfill a number of functions. First, they were to illustrate situations that may occur in a number of typical Alaskan environments. This was accomplished by reviewing sets of typical conditions that may occur based on environmental conditions described in the Alaskan Profiles. Oil spill behavior was also checked in various environmental conditions so that the scenarios would show representative oil/environment interactions for remote inland areas. Next, the scenarios were selected to represent potential real spill situations. That is, they must be typical spill situations that occur frequently, or spill situations that could potentially occur in remote Alaskan areas. This was accomplished by reviewing case histories of inland spills and drawing on the experience of the responsible officials in Alaska. Figure 1 shows the steps taken to develop representative oil spill scenarios.

In summary, selecting spill scenarios involved two basic tasks; selecting typical environmental situations and selecting typical spill situations. Typical environmental situations were developed by reviewing the complete range of environmental conditions that occur in remote Alaskan locations. This was accomplished by listing the various conditions on charts and developing the situations, or combinations of situations, that could occur.

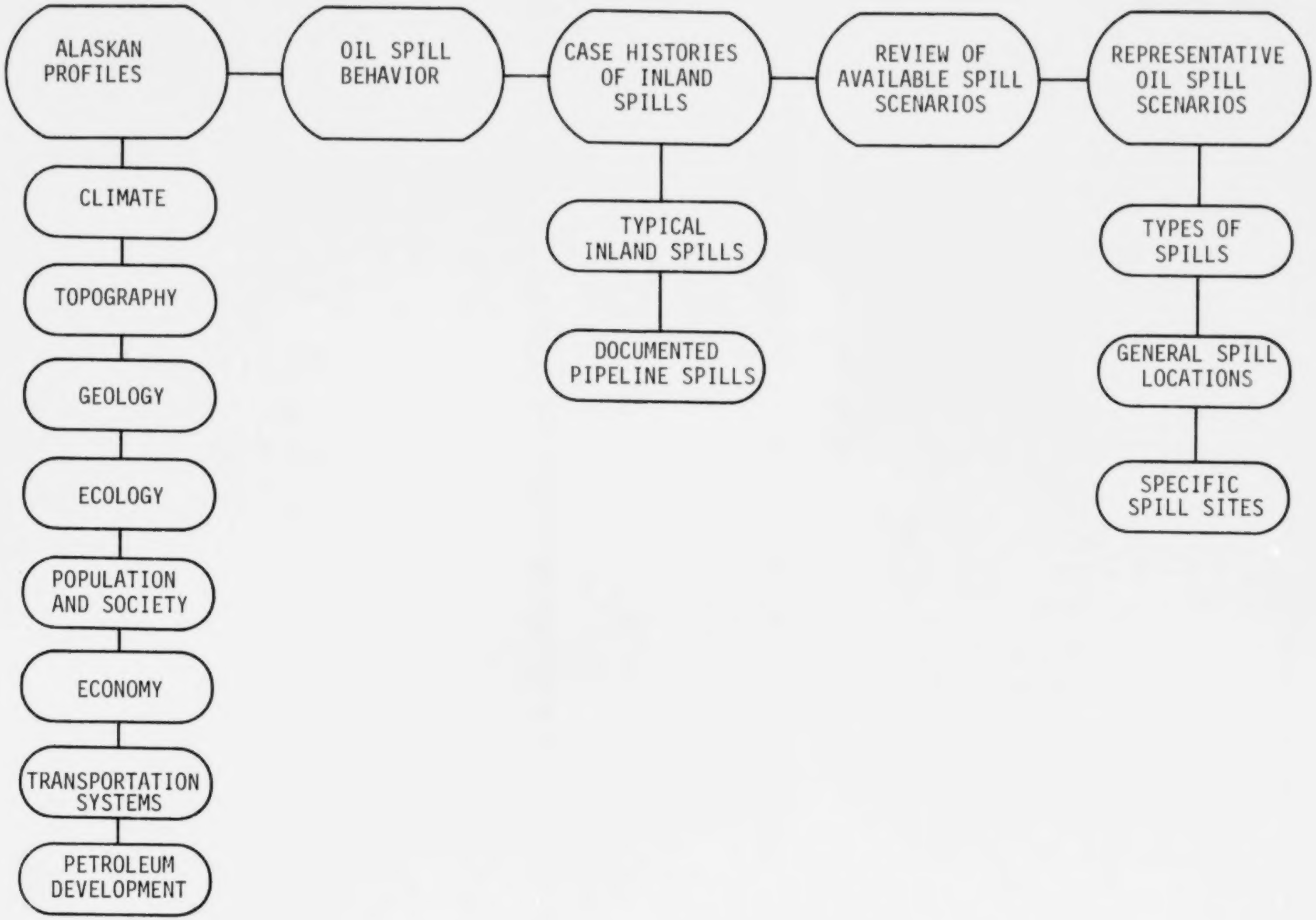
ALASKAN PROFILES
OIL SPILL BEHAVIOR
CASE HISTORIES OF INLAND SPILLS
REVIEW OF AVAILABLE SPILL SCENARIOS
REPRESENTATIVE OIL SPILL SCENARIOS
CLIMATE
TOPOGRAPHY
GEOLOGY
ECOLOGY
POPULATION AND SOCIETY
ECONOMY
TRANSPORTATION SYSTEMS
PETROLEUM DEVELOPMENT
TYPICAL INLAND SPILLS
DOCUMENTED PIPELINE SPILLS
TYPES OF SPILLS
GENERAL SPILL LOCATIONS
SPECIFIC SPILL SITES

Figure 1. Development of representative oil spill scenarios.

Next, the environmental situations in which petroleum development activity occurs, or is likely to occur, were determined. This limited the areas to be considered to some extent. To futher limit alternatives, and to develop a realistic set of possible spill situations, the scenario alternatives were reviewed with the responsible officials in the field. This was accomplished by making a trip to Alaska to confer with federal and state officials, plus the interested representatives from industry.

The meetings in Alaska produced a rather long list of scenario alternatives. This list was sifted many times in order to develop a set of scenarios that was typical of real situations and situations that could be used to illustrate a wide variety of response alternatives and environmental conditions. The complete list of possible scenarios was reviewed, and eight of the most typical inland oil spill situations were identified. These eight scenarios were reviewed again, and a final list of four scenarios was developed for the study.

Oil Spill Scenario Description

After the final selection of spill scenarios was completed, each scenario was described in detail. This description was then used to evaluate available spill response techniques and devices for use in spill response, and to develop effective spill response methods.

Spill Response Techniques and Devices

Spill response techniques and devices were reviewed in terms of their application to the selected spill scenarios. Because of the large number of devices and methods of spill response that are currently available, the evaluation and description was limited to the technology that could be applied to the scenarios selected for analysis. The techniques and devices selected for use in the spill scenarios were evaluated according to the standard spill response functions, that is:

- Detection and surveillance
- Containment
- Recovery
- Transfer
- Storage
- Disposal
- Logistics.

Spill Response Methods and Effectiveness Analysis

This effort consisted of the development and evaluation of spill response methods and devices for each of the spill scenarios. This was accomplished by first developing each spill scenario to an engineering level of detail and then fitting each spill situation to the most suitable spill response method and response devices. Each method was described according to three selected levels of spill response; that is, a minimum level of response, a moderate level of response, and a high level of response. The analysis describes the actions that would be taken for each level of response, an inventory of the equipment and personnel that would be required, and the cost of achieving that level of response.

The description of the spill response procedures was followed by an analysis of the effectiveness of each level of spill response. The effectiveness analysis was performed by first determining the environmental impact of the spill and then the change of impact that could occur with each response effort. This calculation was used to determine a numerical measure of oil spill response effectiveness. Next, the costs of the various levels of response were related to the effectiveness to show a cost/effectiveness relationship. This relationship was finally used to show the marginal advantage of each spill response procedure and the relative value of each procedure in reducing the overall spill impact on the environment.

Recommended Research and Development Initiatives

The spill response technologies applied in the spill scenarios showed a number of deficiencies in dealing with a spill in a remote arctic environment. Further, the spill response effectiveness analysis identified a number of measures and types of response devices which, if perfected, could be used to increase the overall spill response effectiveness. This section summarizes the research and development initiatives that could be used to develop the necessary spill response technology. These R&D programs are identified as to type and in terms of priority representing the level of urgency associated with each requirement.

SECTION 2

CONCLUSIONS

The major conclusions that can be drawn from this study are as follows:

• It is possible to develop a series of oil spill scenarios for remote inland Alaskan environments that illustrate a broad range of physical conditions and spill situations.

• It is possible to characterize spill response effectiveness quantitatively and evaluate the effectiveness and the cost effectiveness of specific spill response procedures. Specifically, it is possible to evaluate spill response efforts in terms of:

- Spill impact
- Reduction of spill impact resulting from various response procedures
- The impact of the spill response procedure itself
- The cost effectiveness of the response procedure including the margin of response effectiveness developed compared to the cost of producing that effect.

• The analysis of spill response effectiveness and cost effectiveness has many benefits. The system produces a numerical result that can provide important insights into a highly complex problem. For example, the analysis of the spill impact and response effectiveness in the four selected scenarios showed that:

- There is a relatively high level of spill response effectiveness for the minimum acceptable level of response and there are only minor improvements for higher levels of response.

- The minimum level of response is the most cost effective, and cost increases much more rapidly than effectiveness as higher levels of response are reached.

- A final massive spill response effort launched to recover a small amount of oil is often neither cost effective nor practical. In fact, the final effort may be more damaging to the environment than leaving the oil in place.

- Suitable equipment to perform some routine spill response procedures in remote inland environments may not be available. Development of the necessary pieces of response equipment shows potential for increasing the effectiveness and reducing the cost of spill cleanup in remote areas.

- There are wide differences in opinion, even among well qualified experts in Alaska, about the kinds of actions that should be taken for site restoration. Important questions that do not appear to be resolved include the treatment of heavily oiled beaches, the disposal of oiled debris and vegetation, and the kinds of policies that should be adopted to minimize the impact on wetlands. Decisions concerning action to take for site restoration must be made on a case-by-case basis; however, it appears that there are no generally accepted criteria for making these decisions. There is a requirement to identify and describe acceptable methods for site restoration.

SECTION 3

RECOMMENDATIONS

The recommendations that follow from this analysis include general recommendations for the management of spill response programs and the specific recommendations for research and development initiatives.

GENERAL RECOMMENDATIONS

- This study has shown that it is possible to evaluate spill response effectiveness and the cost effectiveness of specific spill response procedures quantitatively. It is therefore recommended that this approach be applied to a larger, diverse group of spill response problems that require analysis and quantitative solutions.

- In each of the four spill scenarios evaluated in this analysis, a relatively high level of response effectiveness was achieved with the minimum acceptable level of response, and only minor increases in effectiveness occurred at higher levels of response. Further, the minimum level of response was the cost effective result in each case, and cost increased much more rapidly than effectiveness as higher levels of response were added. It is therefore recommended that a top level policy analysis be conducted to establish what could be considered a practical level of response for typical spill situations. This level of response would not require an unusually costly response procedure that may only achieve a relatively low level of effectiveness and would not encourage intensive response efforts that could actually be damaging to the environment.

- The study determined that there is a general lack of agreement as to the actions that should be taken for site restoration after a spill response effort has been completed. It is therefore recommended that policy guidance be developed to assist field personnel in determining the types and levels of site restoration that should be used.

RECOMMENDED RESEARCH AND DEVELOPMENT INITIATIVES

Cleaning Oiled Snow

Cleaning or processing oiled snow is a routine operation in Alaska, but there is no standard, easy way of doing it. Sometimes the snow and oil are separated by melting the snow in an air berm and skimming the oil off the top of the water. Although this procedure is effective, it is relatively slow and labor intensive, and therefore it is expensive. A single device is needed to perform all of the steps of the process that are presently performed by the response crew at the air berm. It is therefore recommended that a project be established to develop a single, portable device that could be used to separate snow and oil with a minimum requirement for outside energy sources and labor.

Cleaning Sand and Gravel

The problem of cleaning sand and gravel occurs repeatedly in oil spill situations. In this study, oiled gravel in one scenario was cleaned in a snow melter and returned to its original site. This procedure is probably effective in cleaning but not efficient in the use of men and materials. In another scenario, heavily oiled sand was removed from the spill site for disposal. This procedure is also not efficient and is likely to be damaging to the environment. It is therefore recommended that a portable device be developed that is capable of cleaning the sand on site so that removal and disposal is not required.

On Site Burning

Many observers believe that disposal by burning the spilled product in place is a good method of response in some cases. The problem is to identify the cases in which this method is best. Burning with little permanent damage to the environment is possible in certain seasons of the year, with certain kinds of vegetation, terrain conditions, and moisture. Additional information is needed to establish the criteria to determine when burning is the best course of action. It is therefore recommended that a basic research program be initiated to determine the impact of burning in a wide variety of conditions. These tests should be directed toward developing a set of decision-making criteria for use in the field to determine when on site burning should be employed.

Fast Current Containment Booms

The swift, debris laden rivers of Alaska make deployment of containment booms a problem. In many cases it would be desirable to use containment booms but they are not used because existing booms are not effective in these conditions. The following program is recommended to correct this problem:

- Test existing booms to determine which is the best suited for use in high current, shallow stream situations.
- Use a hydraulic model to determine the best ways to deploy booms in these situations.
- If none of the booms available are suitable for this application, design a new boom.

Fast Current Recovery Device

When oil is successfully contained behind a boom in a swift river in Alaska, there remains a problem in recovering the slick. The ideal device would be effective in recovering a thin slick in a fast current. Although many recovery devices are available, they do not meet the requirements of recovering a thin slick in a swift stream. It is therefore recommended that existing devices be tested to determine if any is suitable for this application. If a suitable device is not identified, it is recommended that a new device be developed.

Portable Flaring Burner

Disposal of the recovered product is frequently a problem in Alaska. In remote inland areas, most of the standard methods of disposal are not possible. Further, transporting the recovered product to a site for clean disposal is also a problem. It would therefore be useful to have a portable device that could be used to provide an environmentally safe method of disposal in remote inland areas. To meet this requirement, it is recommended that a portable open flame burner be developed that could be transported to remote areas and used to provide a safe, clean burn of recovered products.

Surface Detection of Product on the Water Table

The area of the spill on a water table cannot generally be determined from the surface. The only way to map the area of the spill is to drill holes in the ground until spill locations are discovered. This method is slow, expensive, and destructive to the terrain. It would be useful to have a device that could sense the presence of underground oil from the surface. It is therefore recommended that a device capable of detecting oil on the water table from the surface be identified or developed.

Site Restoration

There is wide disagreement about the kinds of actions that should be taken for site restoration. In order to provide the basis for making decisions concerning site restoration, it is recommended that a research project be initiated to determine the best ways of responding to some of the following situations:

- Oiled beaches and shorelines
- Oiled debris and vegetation
- Oiled wetlands
- Oiled soils.

Decisions concerning the action to take for site restoration must be made on a case-by-case basis; however, it appears that there are no generally accepted criteria for making these decisions. The proposed research project should identify and describe acceptable methods for site restoration. These methods should be accepted and approved by the responsible State and Federal authorities. The accepted methods of site restoration could then be used for on-site decision making by spill response crews.

Identifying Cost Effective Levels of Spill Response

The analysis of the scenarios investigated in this study shows that the final intensive effort to recover the last small amount of oil is not generally cost effective. In some cases this effort may even be damaging to the environment. It is therefore recommended that an R&D project be established to develop criteria for making the decision on recovering the last traces of a spill. It is suggested that this project review spill response records to obtain field data. In addition, it is recommended that additional data be developed using a cost effectiveness simulation of typical spill problems. This simulation could be used to show the expected results of various response actions and the effectiveness of these actions. The results of the analysis could then be used to develop decision making criteria for use by responsible spill control officials.

SECTION 4

ALASKAN PROFILES

INTRODUCTION

This section describes the Alaskan spill environment for remote, inland areas. This description is rather detailed because the information contained in the profiles is used to select the spill scenarios, and once the scenarios have been selected, to evaluate each site in terms of oil spill potential, spill behavior, spill response, and site restoration.

The information developed in the profiles falls into two broad categories; the natural environment and the human environment. For the purposes of studying the effects of oil spills, the natural environment includes:

- Climate
- Topography
- Geology
- Ecology.

Those aspects of the human environment that are related to oil spill problems include:

- Population and society
- The economy
- Transportation systems
- Petroleum development.

CLIMATE

Alaska is generally divided into four major climatic zones: maritime, transitional, continental, and arctic [1]. The paragraphs that follow describe each of these zones.

Figure 2 shows that the maritime zone includes the Aleutian Islands, the south coast of Alaska, and the Panhandle region of Alaska. Weather in this area is dominated by maritime influences. In particular, the climate is affected by the presence of the Aleutian current which results from the Kurshio and the Oya Shio currents converging in the North Pacific. The maritime zone has small temperature variations, but it is influenced by high levels of precipitation, clouds, and fog. Freezing temperatures are rare and the mean annual temperature is around 5°C.

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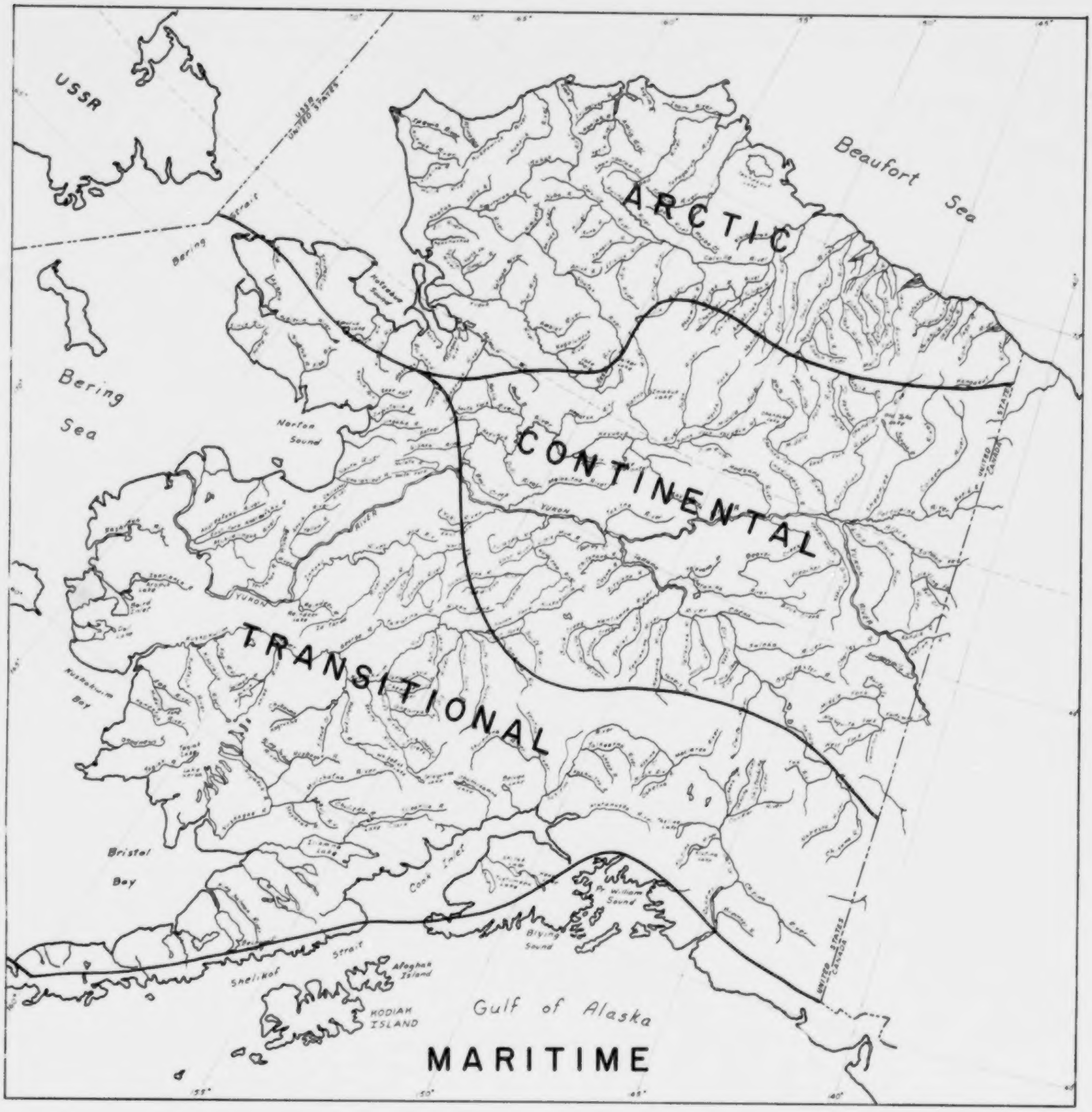
USSR
Beaufort Sea
ARCTIC
Bering Strait
Bering Sea
Norton Sound
CONTINENTAL
YUKON
TRANSITIONAL
Kuskokwim Bay
Bristol Bay
Cook Inlet
Pr. William Sound
Shelikof Strait
Afognak Island
KODIAK ISLAND
Gulf of Alaska
MARITIME
UNITED STATES
CANADA

Figure 2. Climatic zones of Alaska (1).

The transitional zone occurs inland and northward of the maritime zone. Typical weather in this region varies between maritime and continental. Characteristics of the transitional zone include wide temperature variations throughout the day and year. In addition, precipitation, humidity, and cloudiness occur less frequently than in the maritime zone. The mean annual temperature is generally -5° to 2°C. Figure 3 shows the annual variations in climatic conditions for the transitional zone.

The majority of inland Alaska is influenced by the continental zone. This zone exhibits the greatest variation in diurnal and annual temperatures. The continental zone characteristically has low precipitation, humidity, and cloudiness. The mean annual temperature is -10° to -5°C. Figure 4 shows the annual variation of weather conditions in the continental climatic zone.

Weather in the northern portion of the state is classified as arctic. Temperature variations in the Arctic are not as extreme as in the continental zone. Precipitation is extremely light, and strong winds are common. The arctic climate is affected by the ocean in the summer. The mean annual temperature is -10° to -5°C. Figure 5 shows the annual variation in climatic conditions for the arctic zone.

IMPACT OF CLIMATE ON OIL SPILL CONDITIONS

Impact of Climate on Spill Potential

Climate sometimes affects the potential of an oil spill. For example, low temperature and ice formation can cause frost "jack" and failure of various metals susceptible to brittle failure at low temperatures. Many of the methods and equipment used for oil drilling, exploration, and production have not been proven in arctic or subarctic conditions. As a result, they may be more likely to fail when operating in a severe, cold climate.

Impact of Climate on Spill Behavior

Spill behavior is greatly affected by climate. Air temperature, precipitation as snowfall, and ice on water all affect the properties of the oil and the extent of spreading.

Air temperature has a direct effect both on the weathering rate of the oil and oil properties such as viscosity. Warmer temperatures speed the evaporation of lighter, more volatile components. After the light ends have evaporated, the oil is generally less toxic to the environment and has a higher viscosity at the same temperature. The increase in viscosity also changes the spreading characteristics of the slick. Higher viscosity oil has a higher equilibrium slick thickness and a smaller equilibrium areal slick coverage. At low temperatures, the lighter components of the oil may not evaporate as quickly, but the viscosity increases resulting in a decrease in slick movement and coverage.

Other climatic characteristics also affect oil spill behavior. Snow may mix with spilled oil to form a snow/oil mulch. This mixture has a high

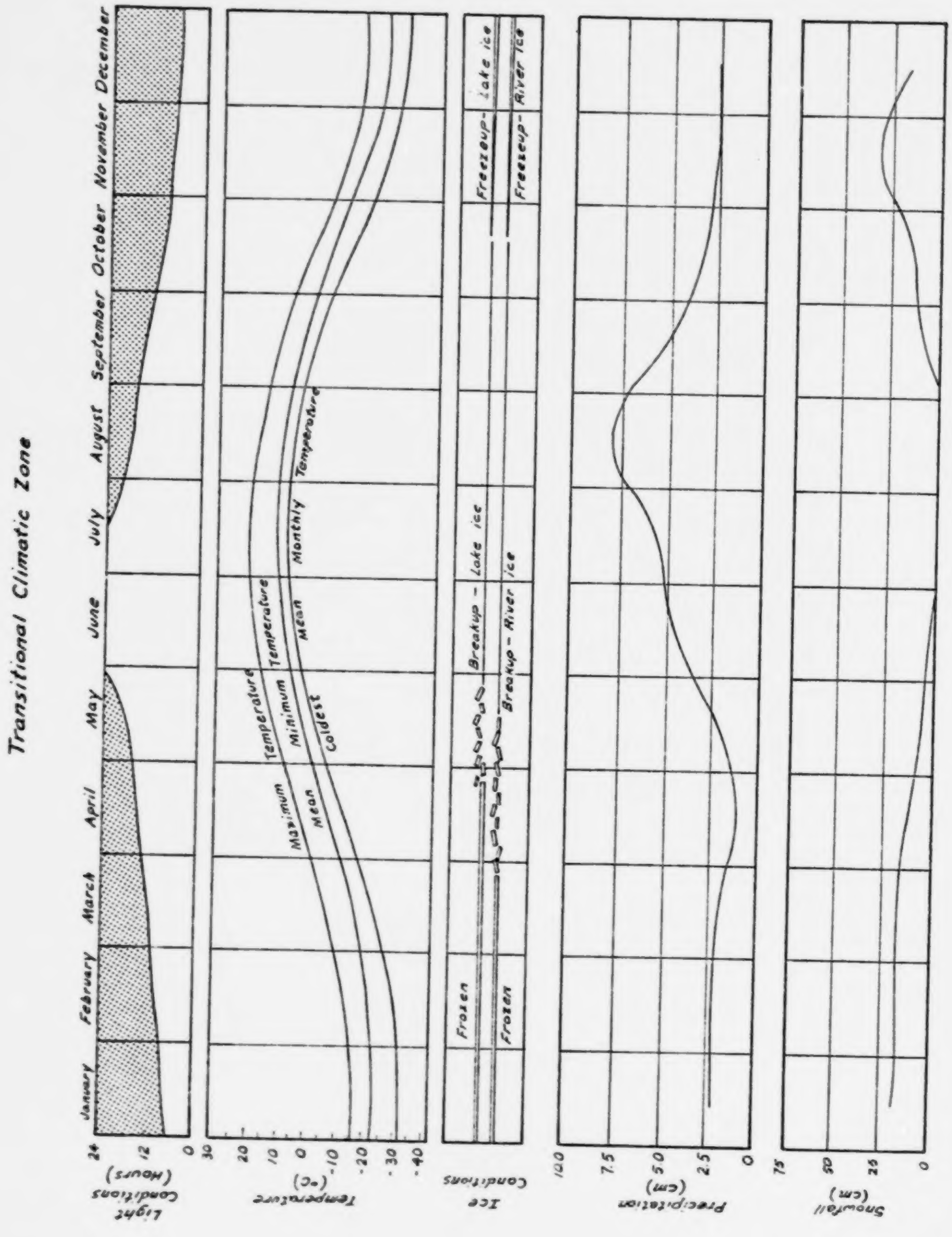

Figure 3. Annual variation in climatic conditions for the Transitional Zone (2).

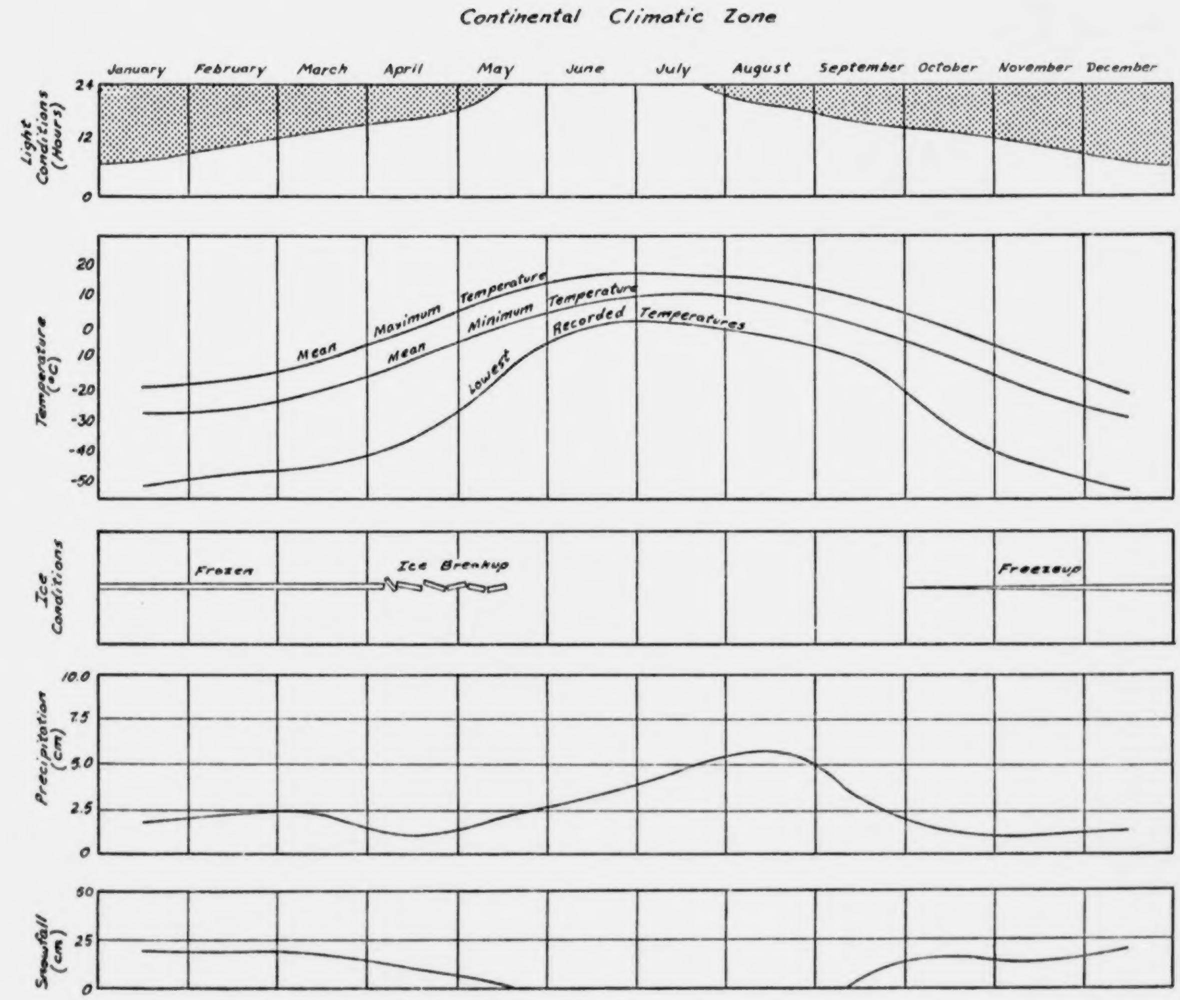

Figure 4. Annual variation in climatic conditions for the Continental Zone (2).

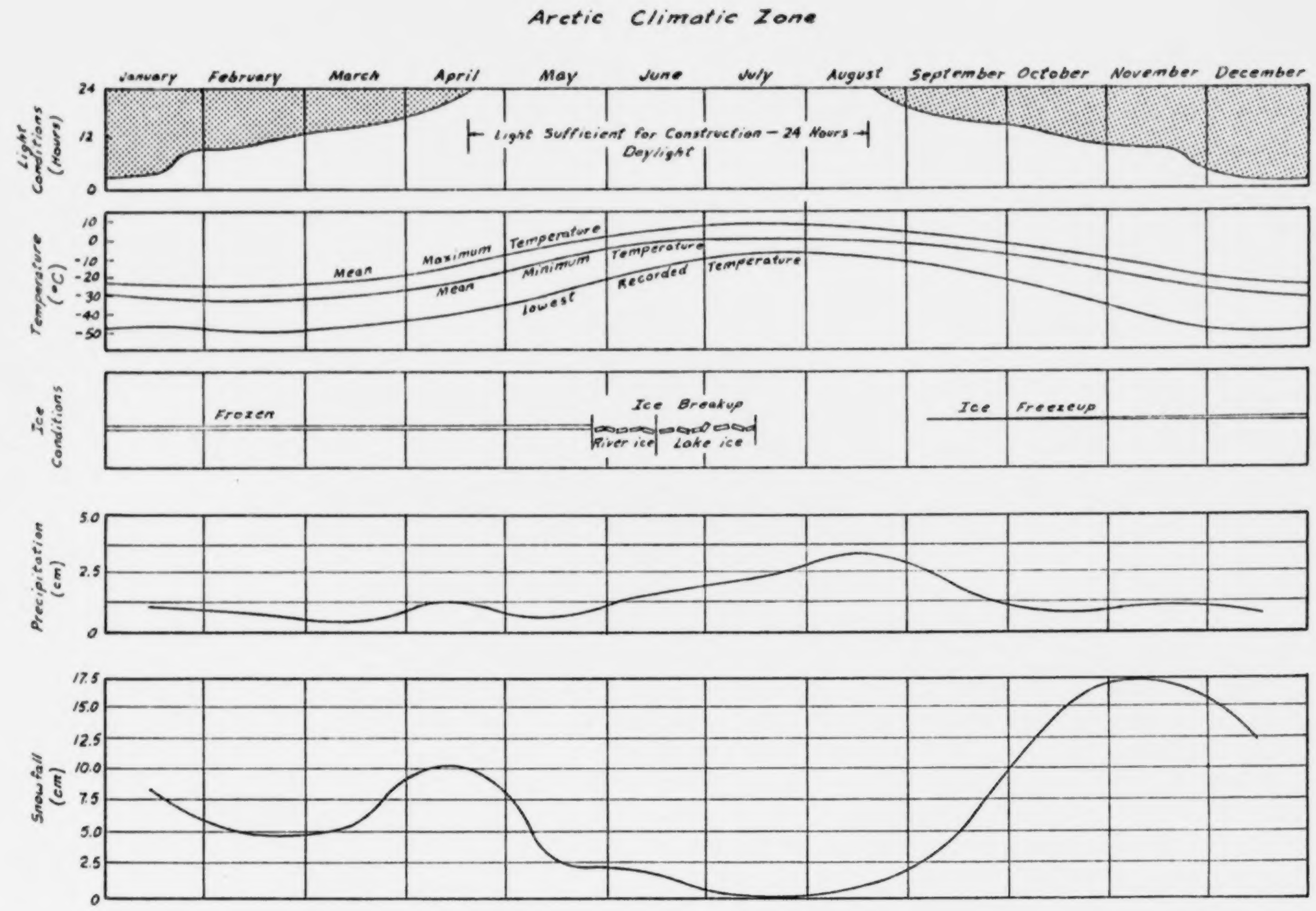

Figure 5. Annual variation in climatic conditions for the Arctic Zone (3).

viscosity and moves very slowly limiting the spreading of the slick. Ice cover in normally open water areas also affects spill behavior. Oil spilled in a broken ice field often accumulates in the openings between the pieces of ice which limits spreading. Oil spilled on solid ice may be prevented from reaching the water at all. Oil spilled under ice may move with the current and the under-ice topography. Wind conditions generally have a small effect on oil movement on land or on water, but then help to weather the oil. An exception to this generalization may occur when strong winds move low viscosity oils across the water or a smooth ice surface that does not have a snow cover.

Impact of Climate on Spill Response

Spill response is affected by climatic conditions such as lighting, temperature, and precipitation. Lack of lighting may adversely affect spill response in the winter in Alaska, especially in the far north where only twilight occurs from late November until late January. Low temperatures may reduce the efficiency of outdoor workers in Alaska. One of the problems is that extremely low temperatures and high winds, common throughout the state in winter, make the air temperature feel much cooler. This temperature/wind combination is called a "chill factor" and can be determined from a chart like that shown in Table 1. Precipitation may also interfere with spill response operations and worker efficiency in responding to an oil spill. Snow may obscure spilled oil by either falling on top of previously spilled oil or acting as a cover for oil moving along the snow/ice or snow/ground interface. The ability of snow to mix with oil to form a mulch obscures spilled oil. On the other hand, snow is also commonly used as a sorbent to recover the oil. The snow is spread on spilled oil and after it becomes saturated, it is picked up by shovel or plow (4).

TABLE 1 COMBINED EFFECT OF AIR TEMPERATURE AND WIND EXPRESSED AS EQUIVALENT CHILL TEMPERATURE

WIND CHILL EQUIVALENT TEMPERATURE (°C)

	Local Temperature	0°	-5°	-10°	-15°	-20°	-25°	-30°	-35°	-40°	-45°	-50°
Wind Speed (km/h)	16	-8	-14	-20	-26	-32	-38	-44	-51	-57	-63	-69
	32	-14	-21	-28	-36	-42	-49	-57	-64	-71	-78	-85
	48	-17	-25	-33	-40	-48	-56	-63	-72	-78	-86	-94
	64	-19	-26	-35	-43	-51	-59	-66	-74	-82	-90	-98
	50	-20	-28	-36	-44	-52	-60	-68	-76	-84	-92	-100

Little danger for properly clothed persons.

Considerable...

Very great...

...danger from freezing to exposed flesh.

Impact of Climate on Site Restoration

Air temperature and precipitation affect the degree to which attempts to restore a spill site are successful. Air temperatures must be suitable for restoration procedures, such as re-seeding and re-vegetation, so that new plant life will be able to take root and live. If the active layer refreezes or if low temperatures damage seedlings, new vegetation may not survive in the area. If permafrost is continuous in the area, care in choosing easily refrozen landfill material may be important to prevent erosion.

Precipitation will similarly affect the success of site restoration. Rainfall may erode new landfill or topsoil before the soil settles or refreezes, or new seedlings may be washed away before they root into underlying soil.

TOPOGRAPHY

Alaska is a land of diverse terrain, characterized by such a range of land forms and inland waterways that many areas might not be recognized as part of the same state by sight alone. The state, the largest in terms of surface area, also contains land of the highest elevation in North America, scattered plains of frozen tundra, and huge rivers that flood extensively in the spring yet almost freeze solid during the winter months. These widely varying and rather severe conditions of topography can be expected to have a profound effect on all aspects of the oil spill problem.

This discussion of topography, as it relates to oil spill conditions, is divided into two parts:

- Land features
- Inland waters.

Land Features

The land in Alaska is basically rugged and mountainous, with relatively little lowland or flatland. Figure 6 illustrates the general trend of the elevations in Alaska by using varying shades to delineate elevation ranges. Two major mountain ranges pass through the state from the eastern to the western border, one in the northern region of the state, the Brooks Range, and the other through the south, the Alaska Range. The tallest peaks in North America occur in the central Alaska Range.

Because of these two massive mountain ranges, Alaska is generally divided into four major physiographic provinces from south to north (1):

- The Pacific Mountain System
- The Intermontaine Plateaus
- The Rocky Mountain System
- The Arctic Coastal Plain.

These provinces are continuations of features of the Western United States and Canada which extend westward. The Pacific Mountain System is a

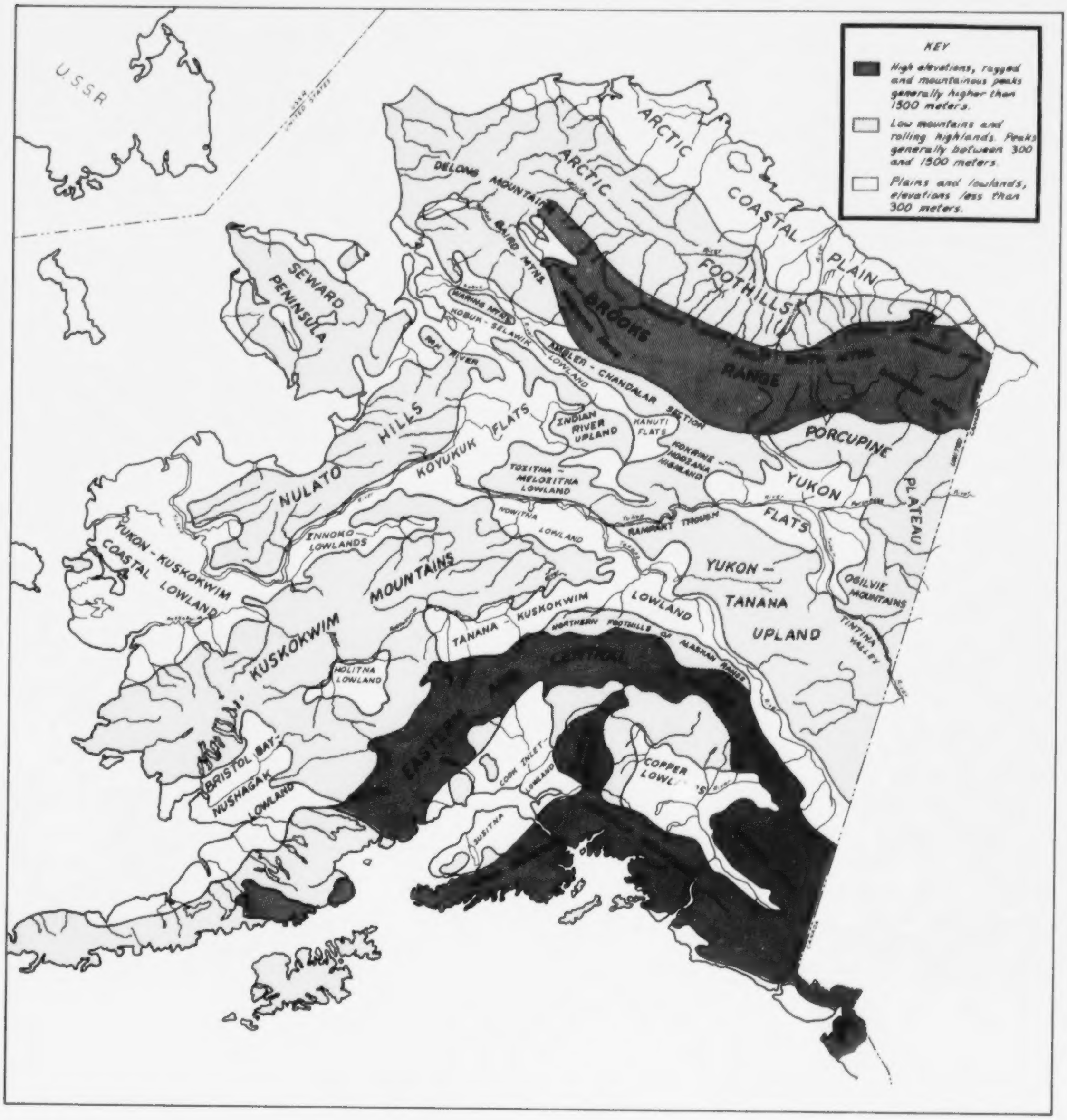
KEY
▨ High elevations, rugged and mountainous peaks generally higher than 1500 meters.
☐ Low mountains and rolling highlands. Peaks generally between 300 and 1500 meters.
☐ Plains and lowlands, elevations less than 300 meters.
USSR
ARCTIC COASTAL PLAIN
ARCTIC FOOTHILLS
DELONG MOUNTAINS
BAIRD MTNS
BROOKS RANGE
SEWARD PENINSULA
WARING MTNS
KOBUK - SELAWIK LOWLAND
AMBLER - CHANDALAR SECTION
FISH RIVER
NULATO HILLS
KOYUKUK FLATS
INDIAN RIVER UPLAND
KANUTI FLATS
KOKRINE - HODZANA HIGHLAND
TOZITNA - MELOZITNA LOWLAND
PORCUPINE PLATEAU
YUKON FLATS
NOWITNA LOWLAND
RAMPART TROUGH
INNOKO LOWLANDS
YUKON - KUSKOKWIM COASTAL LOWLAND
KUSKOKWIM MOUNTAINS
YUKON - TANANA UPLAND
OGILVIE MOUNTAINS
TINTINA VALLEY
TANANA - KUSKOKWIM LOWLAND
NORTHERN FOOTHILLS OF ALASKAN RANGE
HOLITNA LOWLAND
BRISTOL BAY - NUSHAGAK LOWLAND
COOK INLET - SUSITNA LOWLAND
COPPER LOWLANDS

Figure 6. General trends of elevations and physiographic regions of Alaska.

continuation of the Western Coastal Mountain System of the United States and Canada. It consists of two arcs, a southern arc extending along the southern coastline of Alaska, and a northern arc that includes the Alaska Range down through the Aleutian Islands. The Intermontaine Plateaus are basically an extension of the area between the western Coast Mountains and the Rocky Mountains of the U.S. mainland. This area consists of highlands, broad valleys, and lowland basins of alluvial deposits and includes the major river systems of the Yukon, Koyukuk, Tanana, Kuskokwim, and Porcupine. The Northern border of these regions includes the southern slope of the Brooks Range encompassing all or part of the Endicott, Philip Smith, Franklin, Romanzoff, and Davidson Mountains. The southern boundary lies along the Central and Eastern Alaska Range and the Kuskokwim Mountains, which drain northward into the Tanana and Yukon Rivers. The Rocky Mountain System, a continuation of those in Canada and the U.S., includes the peaks and the North Slope of the Brooks Range and the DeLong Mountains. These rocky, rugged mountains drain northward into such rivers as the Colville, Sagavanirktok, and Kuparuk. The Arctic Foothills, consisting of low mountain peaks, wetland, and gravelly soil, serve as a transition from the mountains to the coastal plains. Finally, the Arctic Coastal Plain is an extension of the Great Plains of the United States. This plain is divided in an eastern and western half by the Colville River. The eastern section consists of wide rolling hills and broad plains with shallow braided streams in deep valleys terminating in deltas in the Beaufort Sea. The western region is dotted with thousands of lakes, deep meandering rivers, and many dunes. The entire Arctic Coastal Plain is an area of great potential as a near-term oil producing area.

The four major provinces just described are further subdivided into smaller areas shown in Figure 6. These areas are roughly divided according to terrain similarities and areas of common drainage or some other common characteristic. Table 2 provides a general description of each area named on Figure 6 in order to provide more details on the various areas of Alaskan topography (2,3,5,6,7).

Inland Waters

The inland waters of Alaska, in every physiographic region of Alaska, are important to the inhabitants of the state for community and industrial development, transportation, recreation, and subsistence. The waters occur in several types of deposits such as lakes, streams, marshes, groundwater, ice, permafrost, and surface runoff; but in any form, water in Alaska is a valuable resource in many ways. Figure 7 illustrates the inland surface water systems in Alaska.

The southern regions of the state depend on both surface water and groundwater for subsistence and recreation. Such large river basins as the Copper, Susitna, Kuskokwim, Nushagak, and Kuichak are located in the southern areas. The glaciers in the Alaska Range and Chugach Mountains cause substantial sediment loading into rivers originating in their altitudes. Approximately 48% of the state population lives in the Cook Inlet area of Alaska and rely on freshwater rivers and lakes in the area for their water supply.

TABLE 2. PHYSIOGRAPHICAL AREAS OF ALASKA
This chart describes each physiographic area in Alaska that is susceptible to a remote inland oil spill.

ARCTIC COASTAL PLAIN

Coastal Plain

- Continuous deep permafrost and ice wedge polygons throughout area
- Smooth surface rising from sea level to 185 m at its southern end
- West of Colville River - land is flat with pingos and dunes (10 m max.);
  - rivers meander in valleys 15-90 m deep;
  - thaw lakes cover 50% of the area
- East of Colville River - low hills throughout plain
  - braided rivers cross the plain and form deltas

Coastline

- Chukchi Sea - narrow gravel beaches below inland bluffs
  - steep cliffs in some areas
  - estuaries are common at river mouths
- Beaufort Sea - few beaches and low coastal banks
  - banks slump into sea due to thermal undercutting
  - rivers build broad deltas into the sea

ROCKY MOUNTAIN SYSTEM

DeLong Mountains

- Rugged glaciated peaks 1200-1500 m alt.
- Local relief 450-900 m alt.
- Irregular boundary with northern foothills
- Drained to the north by streams to the Chukchi Sea
- Entire area formed by ancient glaciers

Brooks Range

- Rugged, glaciated ridges 2150-2450 m alt.
- Abrupt rise from northern foothills
- Drainage northward to the Beaufort Sea
- Very few lakes in this glaciated region

Foothills

- Irregular buttes, knobs, ridges, and intervening plains
- Local relief up to 760 m alt.
- North flowing rivers except for Colville which runs eastward for 354 km.
- Icing on rivers in winter
- Thaw lakes and morainal lakes
- Continuous permafrost and ice wedge polygons

TABLE 2 (Con't.)

INTERMONTAINE PLATEAUS

Ambler-Chandalar Section

- East-west aligned series of lowlands and passes 60-600 m
- Brooks Range borders to north, rugged ridges border to south 900-1350 m altitudes
- Drained by surrounding major river systems
- Many lakes and ponds scattered over area

Porcupine Plateau

- Low ridges with gentle slopes and rounded summits up to 1100 m alt.
- Broad, irregular valley floors
- Entire area drained by Yukon River and numerous other rivers flowing in valleys and steep canyons
- Many lakes throughout area

Yukon Flats

- Marshy, lake-dotted area, 90-270 m alt.
- Entire area is river outwash and fans and flood plains
- Silt and gravel terraces slope up to bordering highlands
- Area drained by braided portion of Yukon
- Many lakes and sinks on rising terraces

Kokrine-Hodzana Highlands

- Rounded ridges 600-1200 m alt surmounted by rugged mountains up to 1750 m alt.
- Alluvial valleys
- Drainage by Yukon and Koyukuk Rivers and their tributaries
- Many thaw lakes

Kanuti Flats

- Irregular, lake-dotted plains, 120-300 m alt.
- Scattered low hills throughout central plain
- Drainage by forest-covered belts of Koyukuk and Kanuti Rivers
- Many large thaw lakes

Tozitna-Melozitna Lowland

- Long, narrow rolling plain
- Drained by the Tozitna and Melozitna Rivers which flow in deep gorges
- Many thaw and oxbow lakes

Indian River Upland

- Low, rounded ridges, 450-600 m interspersed with lowlands and flats
- Few mountains rise to 1200 m alt.
- Drainage by surround rivers flowing in deep canyons, major drainage by Koyukuk River
- Numerous lakes and meandering streams

Pah River

- Compact groups of hills and low mountains up to 1200 m alt surrounded by rolling plateaus and broad flatlands
- Drainage by Kobuk, Selawik and tributaries of the Koyukuk River
- Numerous thaw lakes and streams

Koyukuk Flats

- Extensive lowland containing major rivers and large thaw lakes
- Broad rolling silt-mantled plains containing dunes and sinks blend into nearby highlands
- Drainage by Yukon River, its tributaries, and streams with sloughing sides.

Nulato River

- Even-crested ridges, 300-600 m alt with rounded peaks, max peaks at 1200 m
- Narrow, flat-floored valleys
- Local relief generally 150-450 m alt.
- Drainage by Yukon or streams to Norton Sound

Rampart Trough

- Gently rolling hills 150-300 m alt beneath steep highland on all sides
- Yukon flows in narrow, rocky gorge with narrow flood plain
- Thaw lakes and streams which feed the Yukon are scattered over the area

Nowitna Lowland

- Rolling, silt-covered tableland, 75-275 m alt.
- Gentle bedrock hills rise to 450 m
- Dunes cover the southern area
- Drainage by Yukon and Nowitna Rivers
- Numerous lakes throughout area

TABLE 2 (Con't.)

Yukon-Tanana Upland	Tintina Valley	Ogilvie Mountains	Northway-Tanacross Lowland
• Rounded ridges with gentle slopes to 900 m alt • Ridges surmounted by rugged mountains up to 2100 m alt. • Narrow valleys with streams that drain into the Yukon River • Stream and river beds generally in deep V-shaped canyons	• Low open country with rounded ridges up to 750 m alt. • Local relief 300-450 m alt.	• Sharp crested steep mountains with deep valleys • Altitudes to 1500 m with local relief to 1200 m • Ridges are interconnected with few passes • Rivers flow in rock gorges between ridges • Drainage by Yukon River tributaries • Thaw lakes along river beds	• Comprised of three small river basins forming the Tanana River • Northern areas are level plains with dunes • Southern section is gently rolling, moraine covered plain • Rivers enter the area as swift glacial streams, becoming slow and braided near the Tanana • Large lakes and discontinuous permafrost

Tanana-Kuskokwim Lowland	Kuskokwim Mountains	Central and Eastern Alaskan Range	Yukon-Kuskokwim Coastal Lowland
• Varied terrain characterized by outwash fans from the Alaska Range spread along lowland streams • Rivers flow in terraced valleys up to 60 m deep • Dunes cover northern areas • Drainage by glacial streams to the Tanana and Kuskokwim Rivers • Many lakes and sinks throughout the area	• Ridges with rounded and flat summits to 600 m alt. and broad, gentle slopes • Ridges surmounted by rugged glacial mountains up to 1200 m alt. • Flat floored valleys between ridges • Drainage by Yukon and Kuskokwim Rivers • Streams are fast with few lakes	• Three parallel series of ridges 1800-2700 m alt. • Rugged, snowy terrain with few passes • Some tall peaks as high as 6200 m (Mount McKinley) • Crossed by Tanana, Yukon, Kuskokwim and Copper Rivers • Streams are swift and braided • Very few lakes and many glaciers	• Lake dotted, marshy plain rising from the sea to 100 m alt. inland • Ancient craggy mountains rise to 750 m in some places • Many lakes and very slow streams • Yukon-built delta extends into the Bering Sea

TABLE 2 (Con't.)

Northern Foothills of Alaska Range

- Flat-topped ridges up to 1400 m alt. separated by rolling lowlands
- Area of rapid erosion and soft rock
- Rivers flow rapidly in V-shaped canyons
- Drainage to Tanana River

Innoko Lowlands

- Group of flat river floodplains whose steep banks blend into surrounding hills
- Drainage by Yukon and Innoko Rivers
- Many lakes and small streams

Kenai-Chugach Mountains

- Rugged mountains extending to a fjord-indented coastline
- Higher ridges covered by glaciers which melt and supply local streams
- Peaks 2100-4000 m elev. with many broad, rounded mountains

Talkeetna Mountains

- Ice-carved mountains sustaining glaciers up to 15 km long
- Summits lie between 1800 and 2100 m elev.

Wrangell Mountains

- Volcanic peaks rising to 4900 m alt.
- Ice caps and glaciers feed the upper Copper River
- Streams carry heavy sediment load and runoff waters

Copper Lowlands

- Intermontaine basin containing the Copper River
- Eastern section is a smooth plain 300-600 m alt.
- Streams flow in deep, steep-walled valleys

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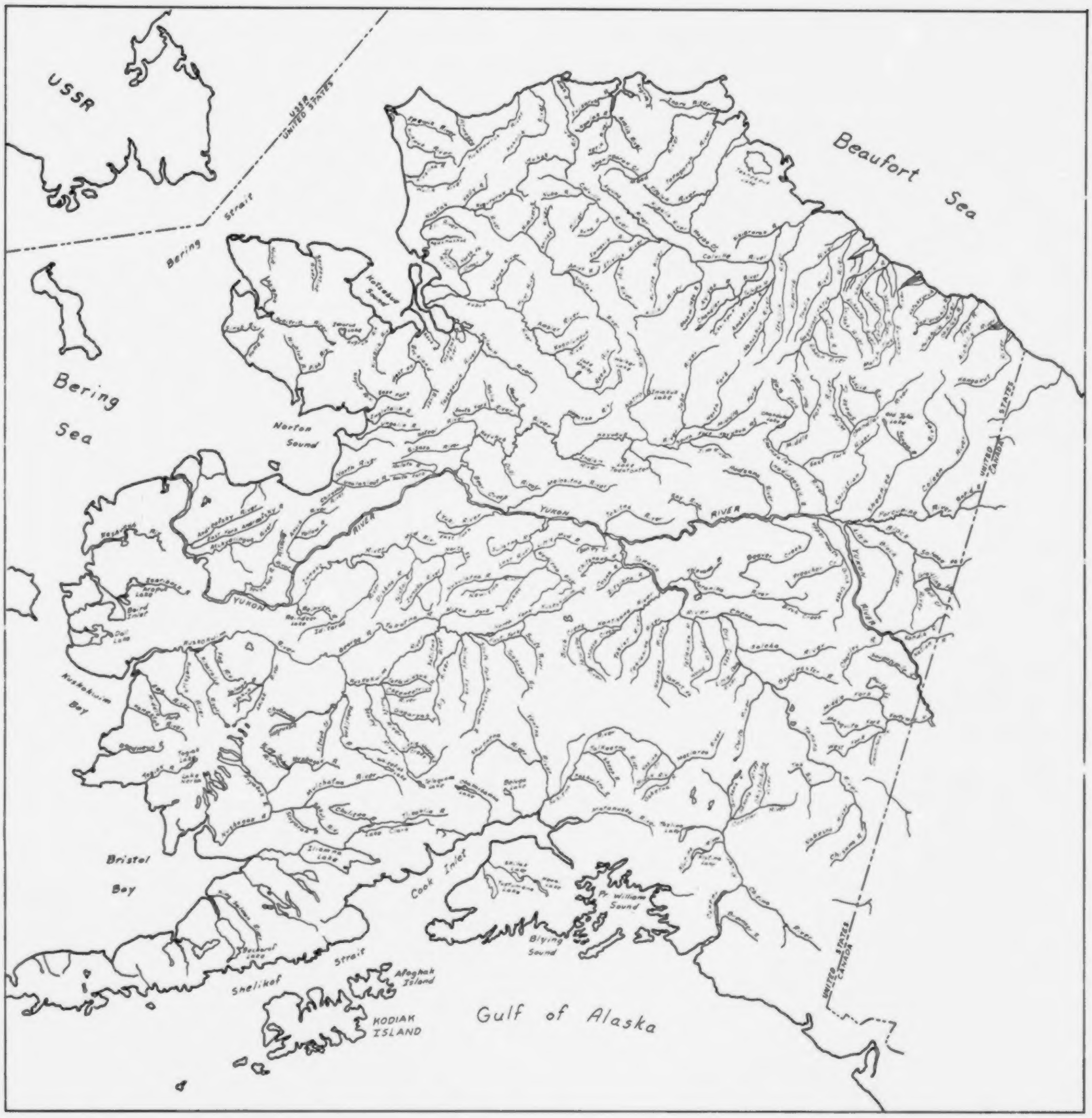
USSR
USSR
UNITED STATES
Bering Strait
Beaufort Sea
Bering Sea
Norton Sound
YUKON
RIVER
Kuskokwim Bay
Bristol Bay
Iliamna Lake
Cook Inlet
Pr. William Sound
Blying Sound
Shelikof Strait
Afognak Island
KODIAK ISLAND
Gulf of Alaska
UNITED STATES
CANADA

Figure 7. Inland surface water systems of Alaska.

Farther north, the Yukon river drains a large percentage of the area between the Brooks Range and the Alaska Range. The Yukon flows from Canada westward across the state to the Bering Sea carrying huge quantities of sediment throughout most of the year. Such large tributaries as the Porcupine, Tanana, and Koyukuk extend the effective drainage area of the Yukon River farther to the north and west. The river discharge fluctuates drastically with the seasons. Low flow occurs in winter because of surface ice and no land runoff. Peak flows occur in late spring and early summer due to snow melt and river ice breakup. Most rivers freeze solid in the winter except the deeper rivers which freeze to about 2.5 to 3 m depths. In spring, flooding is common along most rivers and especially at the lower Yukon River delta. Ice jamming and high sediment loads cause the river to swell miles out of its banks.

The use of groundwater for wells is rare in the Yukon River drainage area because of permafrost conditions; therefore, most communities use surface waters from lakes and rivers for commercial and personal use and spring water for crop irrigation. Some areas in the Tanana and Koyukuk basins use groundwater available by well from floodplain and terrace alluvium. A shallow gallery well is used to capture water laterally, thus increasing the recoverable volume.

The arctic region of inland Alaska has surface waters covering 50 to 75% of its area. These lakes dominate the northern foothills of the Brooks Range and are interspersed with streams and rivers of varying size and flow rate. The Colville River is the largest river of the arctic region. The Colville flows through the central arctic plain and drains into the Beaufort Sea. The river flows through a region of continuous permafrost and is itself frozen 7 to 8 months each year. Smaller rivers are fed by drainage in the Brooks Range and are also commonly frozen through the winter. The major axis of most thaw lakes are aligned 10° to 15° west of north which is the predominant wind direction in the arctic region. Normally these lakes also freeze in winter to a depth of 2 to 2.5 meters, limiting available water in these northern areas in cold weather.

Permafrost, which will be discussed in the next section, causes unique runoff and groundwater problems in the arctic region. Because the frozen ground does not absorb melt water and precipitation, large amounts of runoff water are present in the spring and summer. Much of this water stands as marshes and forms small lakes, but most of it drains into the river systems, causing large stream discharge fluctuations from season to season. Because of the permafrost there is also an absence of groundwater except in the thin active layer above the solid permafrost. Peak runoff occurs in late May to early July.

Surface runoff waters and streams carry large quantities of suspended sediment. This sediment collects as a result of thermal expansion and contraction of rocks, freezing and contracting of water in rock crevices, erosion of rock formations, rock-on-rock abrasion, and glacial erosion. At lower elevations, sediments result from streambed erosion and mudflows. Sediment sizes range from fractions of a millimeter for silt and clays to many centimeters for boulders in mountain streams. Eastern rivers in more mountainous regions flow in narrow valleys and contain much more of the coarse-grained sediment. Large rivers such as the Yukon often carry heavy debris such as logs and tree stumps.

Groundwater occurs in most permafrost regions of Alaska, especially in the arctic region. Groundwater in the active layer is called a "perched" water table. This causes surface flooding in many areas. Water sources in the arctic winter, therefore, include only unfrozen alluvium deposits near rivers and unfrozen water beneath ice cover in very deep lakes. Wells are not common except in these alluvial deposits. Springs in the Brooks Range occur in places where faults are naturally present in limestone, and cause major surface icing in winter.

Flooding generally occurs from late spring to early summer. At these times ice jams in rivers and melting snow causes rivers to overflow many miles beyond their normal banks. Flooding due to rainfall occurs very rarely, generally about every 10 to 20 years in mid-August.

IMPACT OF TOPOGRAPHY ON OIL SPILL CONDITIONS

Impact of Topography on Oil Spill Potential

The topography of the Alaskan region can influence the probability of an oil spill. Rock slides, mud slides, and avalanches on steeply sloping mountains and hillsides may cause damage to oil pipelines and storage tanks resulting in spilled oil. These conditions might cause a spill from an exploratory well by interrupting drilling operations and damaging equipment. Flooding of inland lakes and rivers during ice breakup and snow melt seasons may cause undercutting or flooding of oil storage tank areas, pipeline support footings, or pipeline landfill. High river currents and river debris also make navigation of oil transport barges on riverways very difficult. In the fall there is a danger of barge damage due to late season operation in icy rivers.

Impact of Topography on Oil Spill Behavior

The slope of the ground surface has a direct effect on the speed of movement of a terrestrial oil spill. Similarly, surface roughness such as gravel or small grasses will inhibit the movement of the oil and influence the area that the spill will cover. Swift inland rivers will serve to carry oil spilled on the water downstream quickly. Oil present on water surfaces will spread to a thin slick which results in faster weathering of the oil due to the large surface area of oil exposed to the air. Oil on water that is moving turbulently may tend to be mixed with water and air from winds, forming an emulsion (mousse) or causing some oil to be suspended deeper in the water column, closer to fish and animals on the river bottom. Oil spills that occur during winter when the rivers are frozen would be retained on the top of the ice surface and possibly, in spots, leak under the ice sheet where the oil would follow the underside of the ice with the current until it is contained by under-ice roughness or cavities. As winter advances and freezing reduces runoff, rivers typically have an open void below thick surface ice providing an open route for the movement of spilled oil. A river frozen with a void under the ice is likely to have some water moving deep in the sand or gravel riverbed. Spilled oil could move with this water.

Impact of Topography on Oil Spill Response

Spill response will be affected to a large degree by the topography of the spill site. The ruggedness of the area, slope of the land, and access to the area will affect the type of spill response effort that can be made and, particularly, the type of equipment that can be used in that response. Spill response in the area of rivers will also be affected by current speeds and shoreside terrain and vegetation. River ice and heavy floating debris will also have a significant effect on the spill response effort.

Impact of Topography on Site Restoration

The problems of terrain that affect spill response generally also apply to site restoration. For example, access to the area will determine the means of transporting equipment and materials to the site to be restored. Such characteristics as surface slope, soil stability, and possible flooding of the area will be considered in deciding how site restoration is to be performed. Also, terrain features that prevent oil from being recovered will affect site restoration. For example, oil entering the groundwater may affect plant growth for an extended period of time after the spill.

GEOLOGY

The geology of Alaska also has a significant effect on oil spill problems. The geological features that are related to oil spill conditions are:

- Permafrost
- Earthquakes.

Permafrost

Figure 8 shows that permafrost occurs in Alaska throughout the entire state in some form, except in areas along the southern coast. The areas can be divided into four distinct categories: continuous permafrost, discontinuous permafrost, isolated masses of permafrost, and absence of permafrost (1,8). These categories basically indicate the degree of permeability of the soil in a given area. The availability of groundwater, the risk in constructing engineering structures, and the likelihood of a terrestrial oil spill contaminating subsoil layers and the water table. Permafrost in arctic regions is extremely sensitive ecologically. A brief discussion of permafrost characteristics follows.

Permafrost is defined as any perennially frozen earthen material resulting from continued sub-freezing temperatures (3,9). The duration of

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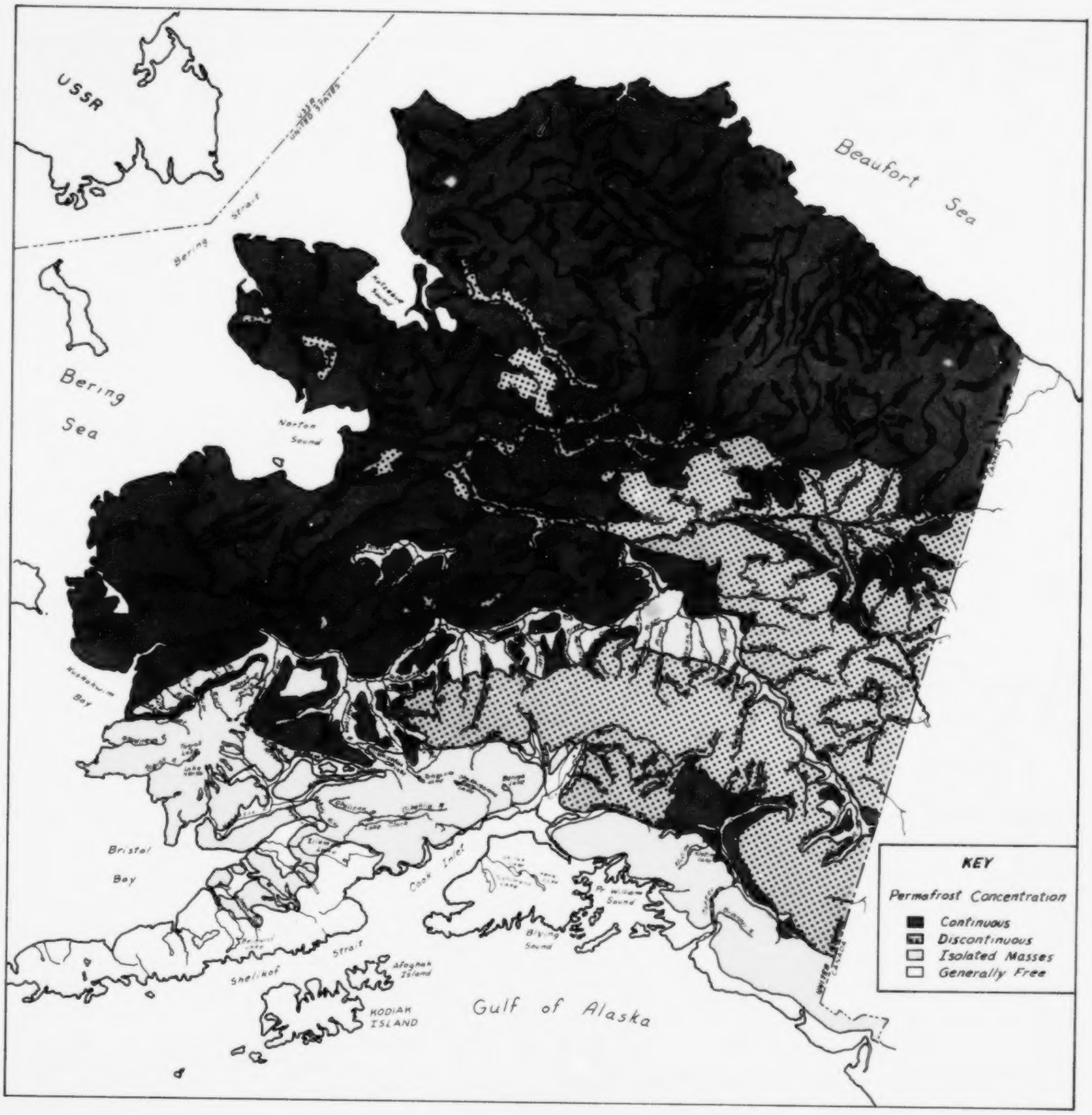
USSR
Bering Strait
Beaufort Sea
Kotzebue Sound
Bering Sea
Norton Sound
Kuskokwim Bay
Bristol Bay
Cook Inlet
Pr William Sound
Blying Sound
Shelikof Strait
Afognak Island
KODIAK ISLAND
Gulf of Alaska
KEY
Permafrost Concentration
■ Continuous
▨ Discontinuous
▒ Isolated Masses
☐ Generally Free

Figure 8. Permafrost occurrence in Alaska.

permafrost ranges from a minimum of one year to tens of thousands of years. In Alaska, the thickness of the permafrost layer varies from zero at the southern coast to 610 meters (2,000 ft) at Prudhoe Bay. The depth of this layer does not uniformly increase to the north, as specific properties of local earthen materials, such as thermal conductivity and molecular makeup, determine the exact characteristics of permafrost in a given area. Local climate, topography, groundwater, vegetation, and geology also affect local permafrost conditions (10). Permafrost, however, is only unique in that the climate in the area is extremely cold causing normal earthen materials to have engineering qualities peculiar to cold regions. Permafrost is reported to cover nearly 22% of the land in North America.

The permafrost layer is divided into three distinct sections--the permafrost table, the suprapermafrost layer, and the active layer. The permafrost table is the extent of frozen ground which is permanently frozen. The suprapermafrost layer is the layer above the permafrost layer and contains the active layer. The active layer freezes in winter and thaws in summer. Unfrozen areas in winter beneath the frozen active layer and the permafrost table are called talik, and often contain groundwater under extreme pressure. Water deposits reduce the temperature fluctuations in the area, causing extreme freeze-thaw cycles. The suprapermafrost lower boundary is that depth at which seasonal variation in ground temperature does not occur. Normally, these depth are between 20 and 30 meters. Ground above this level is very high in ice content, with the upper 4.5 meters of depth being nearly 80% ice in winter. The ice may occur in various forms; for example, as coatings on rocks, as individual grains, as ice lenses, or as ice wedges.

The thawing of permafrost causes uneven changes in topography, called thermokarst topography. Thermokarst topography includes mounds, sink holes, tunnels, caverns, short ravines, lake basins, and circular lowlands. The insulating effect of vegetation is the major factor in preserving topographical features in ice-rich permafrost areas. The removal of surface vegetation and changes in air temperature may trigger thawing of the frozen ground so that distinct changes in landscape and damage to structures occur. Thawing causes solifluction, or mass movement of wet, thawed sediment, which is important to man's activities on permafrost. The thermal balance is very delicate in regions of permafrost such that even vehicle crossings can destroy the terrestrial stability of the area.

Thermokarst topography is prevalent on the Arctic Coastal Plain where poor drainage and cold temperatures combine to aid in the formation of ice-rich permafrost. Many thaw lakes exist in this area, covering more than half of the land area. These lakes are caused by the continuing thaw of permafrost beneath small pools of surface water. These pools continue to grow as thawing persists and are bounded only by ice wedges in the surrounding dry ground. The large lakes on the Arctic Coastal Plain were probably all formed in this manner.

Polygonal grund, or ice wedge polygons, are characteristic thermokarst topography of most permafrost regions. The ground contracts in cold seasons and water freezes in the contraction cracks causing a lattice of ice wedge polygons in the area. As the water freezes to form the wedges, it forces earthen material upward against the wedge causing the polygon outlines to appear in the surface. A stream may intersect ice wedge polygons where a small pool may form. When these pools form along the stream their appearance from the air has resulted in the name of a "beaded stream".

When thaw lakes drain and the underlying permafrost begins to freeze, massive expansion and subsequent upheaval of the ground occurs, leaving a pingo. Pingos appear as large ice-cored mounds frequently having a small lake at the summit caused by thawing of the exposed ice core at the top of the mount. Sizes range from a few meters to 30 meters in height. Some evidence suggests that pingos result from high hydrostatic pressure in the talik bowing up the overlying ground and freezing. Pingos may exist anywhere on the tundra, especially in old lake basins and commonly in marshy well drained areas of valleys. Dense vegetation grows profusely on the well-drained soils of the steep-walled pingos.

Underlying rock beneath the surface soil layer has an important geologic effect on oil spills in mountainous areas where the rock foundation is close to the land surface or actually exposed. The Brooks Range area is primarily Paleozoic, Mesozoic, and Precambrian sedimentary and metamorphic rock, which include sandstone, shale, and limestone. The Alaskan Range varies from east to west, consisting of volcanic quaternary and tertiary ingeneous rocks in the east, mesozoic and paleozoic volcanic rocks in the central range, interspersed with mesozoic sedimentary and metamorphic rock. The western Alaskan Range and Kuskokwim Mountains are mainly sandstone and shale with some limestone and volcanic rock.

Earthquakes

Earthquakes in Alaska are a major geologic factor in the southern and central areas of the state. As shown in Figure 9, the arctic regions of Alaska have had very little recorded earthquake activity; however, shocks may occur but go unrecorded due to the lack of recording equipment in the area. The most severe earthquake activity in Alaska occurs along the southern coast, which is part of the vast continuous seismic belt that rings the Pacific Ocean basin. Frequent tremors are reported, many of which are quite violent. The most violent in recent history occurred in March 1964 in South-central Alaska, centered at College Fiord in Prince William Sound. One hundred and fifteen lives were lost and damage was estimated at 330 million dollars (11).

Earthquakes, such as the 1964 disaster, are associated with great masses of rock and earth fracturing, and displacement, called faulting. The most destructive land movement during faulting is translatory (lateral) landslides. In the Alaskan quake, large tracts of clay-based earth slid shoreward causing extensive damage in the Anchorage business district. Other types of land movement associated with earthquakes are submarine landslides, terrestrial rockslides in glaciated areas where loose rocks are easily moved, avalanches in steep snowy areas, horizontal movement of land masses toward topographic depressions, and altered sediment compaction. Tsunamis, long

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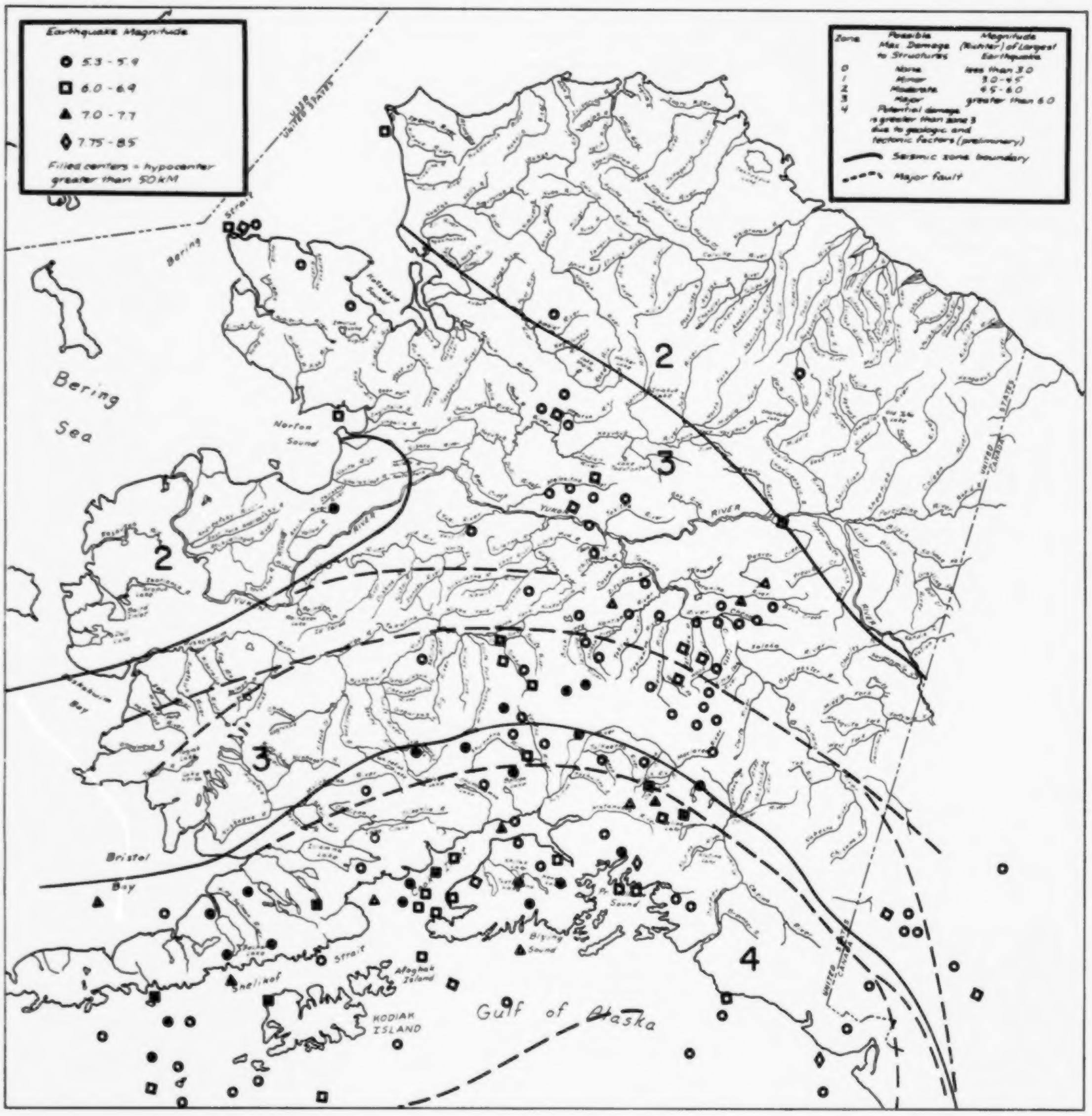

Earthquake Magnitude
● 5.3 - 5.9
■ 6.0 - 6.9
▲ 7.0 - 7.7
◆ 7.75 - 8.5
Filled centers = hypocenter greater than 50 kM
Zone
Possible Max Damage to Structures
Magnitude (Richter) of Largest Earthquake
0 None less than 3.0
1 Minor 3.0 - 4.5
2 Moderate 4.5 - 6.0
3 Major greater than 6.0
4 Potential damage is greater than zone 3 due to geologic and tectonic factors (preliminary)
Seismic zone boundary
Major fault
Bering Strait
Bering Sea
Norton Sound
Yukon River
Bristol Bay
Shelikof Strait
Afognak Island
Kodiak Island
Gulf of Alaska
Prince William Sound
Bering Sound
USSR
United States
United States
Canada
2
3
2
3
4

Figure 9. Earthquake activity in Alaska.

waves generated by the impulse of massive land movement, create large amounts of damage in coastal areas. Farther inland, water table levels are affected, river and lake ice is broken, lakes are drained, streams are dammed by avalanches, and runoff waters increased in sediment load making stream waters temporarily more turbid.

IMPACT OF GEOLOGY ON OIL SPILL CONDITIONS

Impact of Geology on Oil Spill Potential

Geologic considerations such as permafrost and earthquake activity are potential causes of oil spills. Care must be taken when designing and installing pipelines, storage tanks, and structures so as not to cause thawing of the ice in underlying soil. Thawing may result in differential settling of structures and subsequent damage to pipelines in storage tanks. In areas where the upper soil layer thaws in warmer seasons each year, freeze-thaw cycles can be damaging to structural foundations and storage tank foundation pads. Underground piping connecting storage tanks to day tanks may be damaged by a "frost jack", particularly if the pipe connectors are threaded and not welded. The term "frost jack" refers to a wedge of ice that may form under a structure in late winter and lift or "jack" it up causing it to fail. Solifluction action may also pose gradual problems to structural stability on permafrost soils, causing the eventual possibility of spillage.

Earth movements caused by earthquakes will be destructive to any type of structure in the earthquake tremor area, and frequently in areas long distances away. Quakes which cause massive land alterations will damage oil storage facilities, pipelines, refineries, and transportation systems and could cause major blowouts to occur in areas of exploratory drilling. Flooding, common during earthquake activity, might undermine petroleum facilities in the same ways described for spring flooding.

Impact of Geology on Spill Behavior

Permafrost in winter will aid in retaining spilled oil on upper ground surfaces where recovery would be much easier than if the oil had penetrated the ground. The presence of the permafrost and thickness of the permeable active layer in warmer months will determine the extent of oil penetration in Alaskan soils; however, if the oil reaches the water table, recovery of the oil may be more difficult and the oil may enter lakes, streams, and gallery wells months after the spill occurs.

Impact of Geology on Oil Spill Response

Extreme care must be taken in responding to a spill in permafrost areas. Vegetation must be preserved to prevent erosion and ground thaw, and any operations that would cause melting of the ground must be avoided. Regulations set by various agencies of the State of Alaska control operations on frozen ground seasonally to protect permafrost areas. Damage to permafrost may result in severe problems of erosion, particularly if damage occurs on a slope. In its most quiescent form, damage to permafrost may simply leave scars on the ground that last for decades.

Impact of Geology on Site Restoration

As in spill response, care must be taken during site restoration to preserve the permafrost. Restoration of soil layers might include using soils which will readily freeze and support the plants of the area so that new growth will prevent erosion.

ECOLOGY

The Alaskan ecosystem is characterized by vegetation, land animals, birds, and fish. The vegetation is first determined by the soil, the moisture, and the climate. Each vegetation type also supports a particular range of animal life unique to that type. Therefore, the vegetation can be used to classify the various ecosystems throughout the state. Generally, there are eight ecozones: wet tundra, moist tundra, Alpine tundra, low brush-bog muskeg, high brush, bottomland spruce, lowland spruce, and upland spruce-hardwood. The description of these zones, soil type, and associated animal life is shown in Table 3 (2,3,5,6,7,12).

Wet tundra and moist tundra are generally coastal vegetation types, found north of the Brooks Range and bordering the Bering Sea and Bristol Bay. The wet tundra occurs in the lowest elevations where the stream meanders are most pronounced. Farther upland the ground slope allows better runoff so that small brush can grow in the drier areas. These are grouped together in Figure 10 as Tundra.

South of the Brooks Range and in the interior region, the major river floodplains are classified as low brush-bog muskeg, bottomland spruce-poplar, or lowland spruce-hardwood. Generally the river is immediately bordered by low brush, or bottomland spruce depending on the soil moisture content. These areas are surrounded by extensive stands of black spruce in the lowland spruce areas. In Figure 10 these areas are grouped as Lowland Vegetation.

The foothills of the interior region of Alaska and the well drained banks of rivers north of the Brooks Range support upland vegetation. Only high brush flourishes above the Arctic Circle. Elsewhere upland vegetation is characterized by the upland spruce-hardwood forests. As shown in Figure 10 Upland Vegetation spans the central interior of the state.

The high elevations of the Brooks and Alaska Ranges are glacial covered, or frozen barren ground covered by sparse vegetation. Minimal soil, and windswept conditions inhibit the growth of large vegetation. These areas are classified as alpine vegetation in Figure 10.

The soils of Alaska can generally be considered as poorly drained and having a peaty surface and shallow permafrost table. Only soils in higher elevations, on steep slopes, or found in flood plains are well drained. Since a large part of the state is covered with wet to moist tundra or low brush-bog muskeg, water tolerant plants such as mosses and lichens predominate. In less moist areas, grasses and sedges develop. On drier soils, larger plant species such as trees can become established. However, tall heavily forrested areas occur only along coastal regions.

TABLE 3. DESCRIPTION OF VEGETATION, SOIL AND ANIMAL DISTRIBUTION IN ALASKA

ECO-ZONES	SOILS	VEGETATION	MAJOR MAMMALS	BIRDS
Wet Tundra: Covers much of the coastal plain north of the Brooks Range and bordering the Bering Sea. There is little topographic relief in this area. Standing water is almost always present in the summer and numerous shallow lakes and marshes are common.	These soils are generally loams, silt loams, or stratified silt loam and fine sand. Fibrous peat extends into the permafrost and overlays much of the area. Soils are poorly drained peat or peaty surface layer with shallow permafrost table. Soils are generally saturated.	Almost continuous coverage of grasses and sedges rooted in mosses and lichens. Dwarf shrubs may be found on slightly raised ridges. Rooted aquatic plants such as horsetail, pondweed, and bur reed are found in standing water.	Brown-Grizzly Bear, Wolf, Wolverine, Caribow, Shrew, Lemming and Voles, Fox, Weasel.	Swans, geese, Dabbling Ducks, Diving Ducks, Loons, Grebes, Raven, Marsh Hawk, Jaegers, Shorebirds, Open Country Owls.
Moist Tundra: Occurs along old beach lines and rolling coastal hills, on the foothills of the Brooks range, and the high foothills of the Alaskan Range.	This soil is dominantly silty loam, but textures range from sandy to clayey. Soil is usually wet and poorly drained. A thin peat surface layer occurs over shallow permafrost table.	Wide variety of low growing shrubs, herbs, grasses, and sedges rooted in a continuous mat of mosses and lichens. Numerous colorful flowers occur during summer.	Brown-Grizzly Bear, wolf, Wolverine, Caribou, Fox, Shrew Lemming and Voles, Muskow, Squirrel, Measel.	Gulls, Raven, Bald Eagle, Jaegers, Dabbling Duck, Diving Duck, Geese, Swans, Grebes, Loons, Sandhill Crane, Perching Birds, Hawks, Open County Owls, Shorebirds, Ptarmingan.
Alpine Tundra: Occurs on rocky ridges and mountain tops of the Alaskan, Brooks, and Chugach Mountains.	Characteristically shallow silt loam overlying gravelly loam. Bare rock and stoney rubble common. Soil is well drained with thin dark acid surface layer and deep permafrost table. Slopes exceed 12%.	Typical Alpine tundra species are lichens, blueberry and cranberry. In windswept areas lichens, lupine, aster, and cinquefoil grow. Protected areas support alpine azalea, arctic willow, and mountain avens.	Dall Sheep, Hoary Marmot, Brown-Grizzly Bear, Wolf, Wolverine, Caribou, Fox, Lemming and Voles, Squirrel, Shrew.	Ptarmigan, Raven, Golden Eagle, Hawk, Gyrfalcon, Perching Birds, Shorebirds, Open Country Owls.
Low Brush - Bog Muskeg: Occurs at confluents of major rivers, and in flooded drainage areas. Typically found in areas of oil stream channels and horseshoe lakes.	Commonly loams, silt loams, or stratified silt loam and fine sand. Fibrous peat extends into permafrost. Soils are poorly drained peat or peaty surface layer over shallow permafrost table.	Vegetation varies from uniform coverage by sedges and moss to continuous stands of low brush, to shrubs and herbs growing on ridges and aquatic mosses growing in wet depressions.	Brow-Grizzly Bear, Wolf, Wolverine, Caribou, Moose, Beaver, Coyote, Fox, Weasel, Ermine, Lynx, Hare.	Dabbling Ducks, Diving Ducks, Geese, Swans, Grebes, Loons, Sandhill Crane, Marsh Hawk, Gyrfalcon, Shorebirds, Open Country Owls.

ECO-ZONES	SOILS	VEGETATION	MAJOR MAMMALS	BIRDS
High Brush: Occurs on the floodplains of rivers north of the Brooks Range. Generally found on coarse gravelly alluvium.	These soils are typically loams, particularly silty but also startified loam and sand. Soil ranges from well drained in flood plains to poorly drained soils with peaty surface and underlain by a shallow permafrost table.	High brush characterized by dense thickets of willow, alder, and birch with wide variety of lower shrubs, herbs, grasses, ferns, and mosses as understory.	Black and Brown Bear, Moose, Wolf, Wolverine, Hare, Fox, Lynx, Weasel.	Ptarmigan, Raven, Hawks, Owls, Perching Birds
Bottomland Spruce-Poplar: Occurs along floodplains of rivers south of the Brooks Range. Generally found on well drained gravelly soils.	Soil is commonly silt loam to sandy loam with some deep fibrous peat. Stratified silt loam and sand are also found. Soil ranges from the well drained stratified materials in floodplains to poorly drained soils with peaty surface layer and shallow permafrost table.	Characterized by tall stands of white spruce with balsam poplar. The understory includes high and low shrubs, ferns, mosses, and lichens.	Hare, Squirrel, Beaver, Wolf, Fox, Black and Brown Bear, Wolverine, Lynx, Moose	Grouse, Raven, Woodpecker, Hawks, Perching Birds, Woodland Owls.
Lowland Spruce-Hardwood: Occurs in the intermontaine basins of lowlands of interior Alaska. Typified by the major watershed areas for rivers.	Loams, silt loams, or stratified silt loam and fine sand are common. Fibrous peat also extends into permafrost. Soils are poorly drained peat or peaty surface layer with a shallow permafrost table.	Extensive pure stands of black spruce or black spruce mixed with tamarack, birch, aspen, and poplar characterize the spruce-hardwood community. The understory includes willows and low-brush cranberry rooted in a thick mat of Sphagnum mosses and sedges.	Black and Brown Bear, Lynx, Fox, Wolf, Wolverine, Moose, Hare, Squirrel.	Spruce Grouse, Raven, Hawks, Woodland Owls, Perching Birds, Woodpeckers.
Upland Spruce-Hardwood: Occurs in higher elevations on well drained soils from the south slope of the Brooks Range to the north slope of the Chuchach and Alaskan Range	Typically gravelly and stony loam soils. Soils range from well drained thin soils with dark, acid surface layer and deep permafrost table to poorly drained soils with peaty surface layer and shallow permafrost table slopes exceed 12%.	White spruce with scattered birch or aspen is common on south facing slopes while black spruce is found on northern exposures and poorly drained flat surfaces. Understory consists of spongy moss and low brush on the cool moist slopes, grasses on dry slopes, and willow and alder with dwarf birch in the high open forests near timberline.	Hare, Squirrel, Wolf, Fox, Black and Brown Bear, Weasel, Wolverine, Lynx, Moose, Caribou, Marten, Ermine.	Ptarmigan, Raven, Grouse, Woodland Owls, Hawks, Woodpeckers, Perching Birds.

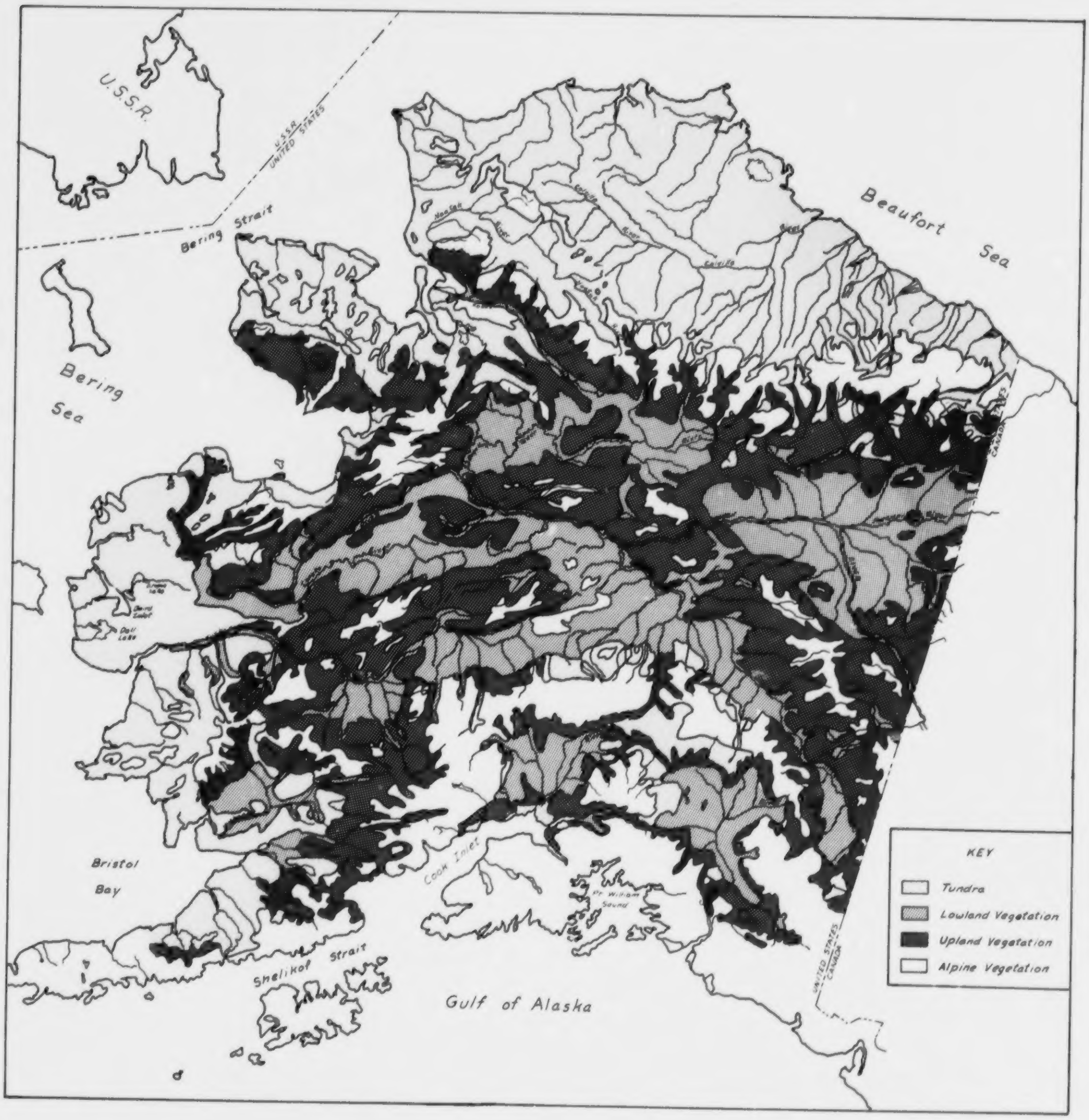

U.S.S.R.
USSR
UNITED STATES
Bering Strait
Beaufort Sea
Bering Sea
Bristol Bay
Cook Inlet
Pr. William Sound
Shelikof Strait
Gulf of Alaska
UNITED STATES
CANADA
KEY
Tundra
Lowland Vegetation
Upland Vegetation
Alpine Vegetation

Figure 10. Distribution of vegetation in Alaska.

The range in climatic conditions and topography of the state causes some land animals to be restricted in their ranging; therefore they cannot occur in every instance for a particular ecozone. Table 3 suggests the species which are generally found for each ecozone. Species such as mink, squirrel, beaver, muskrat, and arctic fox are not capable of major migrations and so become geographically restricted. Some larger animals such as deer and dall sheep are more geographically restricted, remaining in terrain which offers the greatest protection. Other large animals, predominantly moose and caribou, travel in herds and migrate throughout the state so that seasonally they could be geographically restricted in occurrence by ecozone.

The bird category generalizes birds of each ecozone by orders or families. There are twenty major orders of birds in North America. Of these, basically ten orders appear in Alaska. These are the loons; grebes; waterfowl including swans, geese, diving ducks, and dabbling ducks; hawks and falcons including the eagle, hawk, gyrfalcon, and osprey; gallinaceous birds including ptarmigan, and cranes; shorebirds and gulls including the jaeger, gull, and tern; owls including woodland owls and open country owls; woodpeckers; and perching birds which is the largest order and includes most medium to small land birds. Many of these birds, particularly waterfowl and shorebirds, are migratory and leave the Arctic during the winter, traveling as far as the eastern United States. Other species, particularly raptors including the eagles, hawks, gyrfalcons, osprey, and owls are permanent to the areas and are much more sensitive to environmental changes. The low marshy areas, particularly the wet and moist tundra and low brush-bog muskeg, are the primary nesting and feeding grounds for most of the species.

IMPACT OF ECOLOGY ON OIL SPILL CONDITIONS

Impact of Ecology on Oil Spill Potential

The ecosystem will contribute minimally to the potential for an oil spill. Subsidence of the ground due to melting of the permafrost caused by loss of the vegetative cover could lead to a pipeline failure. Accidental spills may also be caused by bullet holes in a tank or pipeline due to hunting. A vehicular spill may also occur in a petroleum truck overturns trying to avoid an animal. In general, however, a spill would not be caused by the ecosystem.

Impact of Ecology on Oil Spill Behavior

The behavior of oil spilled on land will be strongly influenced by the surface soil and vegetation. The soil type will determine how quickly the oil will be absorbed into the ground, and how easily it can spread in the soil. The vegetation cover will also aid in confining a spill from spreading on the surface. The surface spread rate will be a function of the vegetation cover and density. The drainage of the active layer will determine whether the spilled oil can be carried through the soil or spread on its surface.

Impact of Ecology on Oil Spill Response

Spill response will be significantly influenced by considerations for both vegetation and animal life. The arctic vegetation is often very fragile and marginally established. Major cleanup efforts, including off-road vehicle use or mechanical scraping of the vegetated surface layer, may result in long-term destruction of the vegetation and degradation of the underlying permafrost. Particular response methods may also be restricted seasonally because of animal mating or migration habits.

Impact of Ecology on Site Restoration

The considerations for site restoration are similar to those for spill response. An additional impact of the spill occurs at the time of site restoration. In revegetating an area and restoring the natural drainage, it may not be possible to re-establish the same vegetative community as existed prior to the spill. Although the new vegetation may stabilize the ground, it may not support the animal community that occurred before the spill. Animals that depended on the original vegetation may disappear while those requiring the new type may replace them (3). Judgements must be made as to the overall impact of a particular restoration procedure.

POPULATION AND SOCIETY

Population Distribution

The population of Alaska has dramatically increased during the 1970's. Figure 11 shows the 1979 Alaskan population (13). Approximately 60 to 70 percent of the population in Alaska lives in the urbanized areas of Anchorage, Fairbanks, Juneau, and Ketchikan. The remaining more remote areas of Alaska are inhabited primarily by native Alaskans living in small villages. The population of these villages is generally stable or decreasing since many natives have been migrating to the urbanized areas which now contain 40 percent of the total state native population. This migration results from a search for better living conditions and the opportunities for alternatives to the traditional life (14).

The growth of the native peoples in Alaska is relatively rapid, with the population having almost doubled in the last two decades. Because of this rapid growth, the average age is very young, approximately 18, with 43 percent of the people below 15 years of age. As a result, supporting the young has become a burden to the smaller group of working-aged natives. Competition for work positions is increasingly more severe for natives because the non-native population is growing even more quickly and has a high percent of prime working-age immigrants. Migration for employment has left rural native villages particularly depleted of working-age people. Many villages are left with the very young and the very old, both categories not well able to support themselves. Native Alaskans also have larger families than non-natives, usually about 6 persons per family, which causes housing problems as well as employment problems.

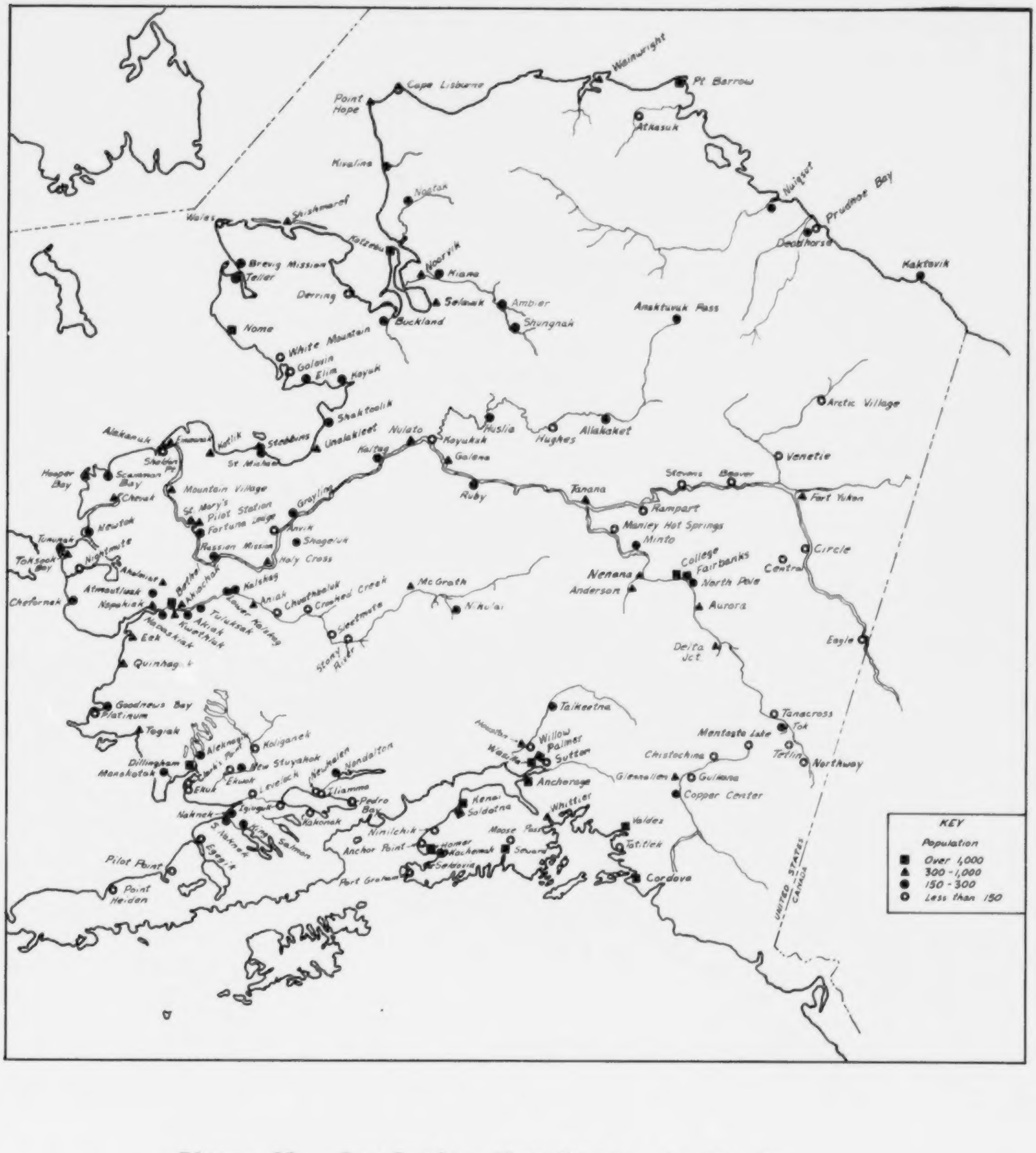

Wainwright
Pt Barrow
Cape Lisburne
Point Hope
Atkasuk
Kivalina
Noatak
Nuiqsut
Prudhoe Bay
Deadhorse
Kaktovik
Wales
Shishmaref
Kotzebue
Noorvik
Kiana
Brevig Mission
Teller
Deering
Selawik
Ambler
Shungnak
Buckland
Nome
Anaktuvuk Pass
White Mountain
Golovin
Elim
Koyuk
Shaktoolik
Arctic Village
Alakanuk
Emmonak
Kotlik
Stebbins
Unalakleet
Nulato
Koyukuk
Huslia
Hughes
Allakaket
Sheldon Pt
St Michael
Kaltag
Galena
Venetie
Hooper Bay
Scammon Bay
Mountain Village
Ruby
Tanana
Stevens
Beaver
Fort Yukon
Chevak
St. Mary's
Pilot Station
Fortune Ledge
Grayling
Rampart
Manley Hot Springs
Newtok
Anvik
Shageluk
Minto
Tununak
Toksook Bay
Nightmute
Russian Mission
Holy Cross
College
Fairbanks
Circle
Central
Akolmiut
Bethel
Akiachak
Kalskag
Nenana
North Pole
Chefornak
Atmautluak
Napakiak
Aniak
Chuathbaluk
Crooked Creek
McGrath
Anderson
Aurora
Nikolai
Akiak
Kwethluk
Tuluksak
Lower Kalskag
Napaskiak
Eek
Sleetmute
Stony River
Delta Jct
Eagle
Quinhagak
Goodnews Bay
Platinum
Togiak
Taikeetna
Tanacross
Tok
Mentasta Lake
Houston
Willow
Palmer
Sutton
Wasilla
Chistochina
Tetlin
Northway
Aleknagik
Koliganek
Dillingham
Clark's Point
New Stuyahok
Newhalen
Nondalton
Manokotak
Ekuk
Ekwok
Levelock
Iliamna
Anchorage
Glennallen
Gulkana
Copper Center
Naknek
Igiugig
Pedro Bay
Kenai
Soldotna
Whittier
Valdez
Kokonak
Ninilchik
Anchor Point
Homer
Kachemak
Moose Pass
Seward
Tatitlek
S. Naknek
King Salmon
Egegik
Pilot Point
Port Graham
Seldovia
Cordova
Point Heiden
UNITED STATES
CANADA
KEY
Population
■ Over 1,000
▲ 300 - 1,000
● 150 - 300
○ Less than 150

Figure 11. Population distribution in Alaska.

Education

In urban areas all children attend district schools with native children being a small minority of the total school population. Rural areas have two school systems, Bureau of Indian Affairs Schools and State Operated Schools. In the 53 Bureau of Indian Affairs (BIA) schools, native children comprise virtually the entire enrollment. Other State Operated Schools (SOS) in rural areas serve to educate children in all rural areas not served by BIA schools except the Arctic Slope and Koniag regions. In all, 70 percent of the school-age native population and 60 percent of the non-native population were enrolled in school in 1970. Since the 1970's, native school attendance has increased 50 to 200 percent in district schools, 75 to 300 percent in SOS schools, and has declined slightly in BIA schools because of increased emphasis given to the state and district schools.

Health

Health conditions among Alaskans have generally been improving over the past twenty years. Improved medical care has reduced the death rate while high birth rates continue to raise the percentage of youthful population in the state. Natives, however, do have higher rates of age-specific health problems and deaths than do non-natives who generally have had better medical attention before coming to the state.

Alaskan natives have generally higher proportions of preventable health problems than do non-natives; however, these differences have decreased rapidly since 1950. Preventable health problems, often caused by poor living conditions and poor preventive care, include infectious diseases, respiratory diseases, congenital problems, and certain infant deaths. Included in these diseases are tuberculosis, pneumonia, influenza, and other respiratory diseases. Such illnesses are related to life in a harsh environment and in crowded, sub-standard quarters. State health problems are directed toward relief of these problems; however, even the decreasing rates of occurrence of these diseases remain high above national standards.

Nutritional data related to the diet of Alaskans is generally not available; however, since the native diet often depends on subsistance hunting and fishing, it is known that these people consume high protein foods and lack certain essential vitamins and minerals. The diet of the non-native population is generally more balanced and consists of foods that have been properly preserved and handled. Dietary differences are most significant between urban and non-urban areas.

Accidental death rates in Alaska are very high. These rates can be attributed to extreme environmental and occupational hazards, particularly for native Alaskans. Water transport accidents are the largest single type of accident among natives, and occur in regions where water transport is particularly important to native employment and subsistance activity. Motor vehicle deaths occur as frequently in Alaska per 100,000 population as in the lower 48 states; however, the air accident rate is much higher, as air travel is commonly the only means of transportation between points in the state. Another contributing factor is the fact that common air vehicles are small, and they fly in extremely adverse weather conditions. Other accidental death rates from fires, poisoning, exposure, hunger, thirst, insect bites, stabbing, drowning, and shooting are also generally higher than the U.S. norm.

Housing

Housing is perhaps the most serious problem confronting peoples in remote areas of Alaska. The harsh climate, low incomes, high transportation costs, high construction and heating costs, and the low population density have held the quality of construction at low levels. Native Alaskan housing is overcrowded and lacks utility services, while non-native Alaskan homes generally do not have these problems. Overcrowding in native homes is dominant in the rural Western and Arctic Slope areas where construction, heating, and transportation seem to be the limiting factor. Even higher income people in these areas remain in overcrowded residences. Statistics show, however, that non-natives of relatively lower income levels do not generally live in overcrowded housing or lack utilities. The estimated value of native housing emphasizes differences in housing conditions. For example, in 1970 the average statewide value of a home was $23,000, while the native housing average value was about $4,500. Since Alaska is a state with relatively high home prices, this estimate indicates that native housing has only limited market value.

Utilities

In rural areas, telephone service, electricity, water, and sewage disposal are generally not available. A single village telephone and sufficient electric power for a few light bulbs are the extent of utilities in most villages. In western and northern areas, telephone and electric lines are rare but less costly than water and sewage service.

Employment Patterns

Villagers in remote areas rely both on the cash economy and subsistence livelihood as sources of income. Increasing dependency is evident on wage income for the purchase of food, fuel, and utilities; however, cash and self-subsistence is still common from fishing, trapping, hunting, and gathering wild produce. The entry of natives into the cash economy may depend on times of traditional tribal activities or times of family uprooting and movement.

The unemployment among natives cannot be attributed to a shortage of jobs, as Alaska's economy has generally been improving. Wage and salary employment increases at about six percent per year fairly uniformly throughout the state. The largest increase in available jobs occurs in the urban centers of the state. Urban areas have 90% of the new job openings, making the best jobs accessible to the many non-native city dwellers. Government provides an important source of employment for the natives. In most areas, about 50% of the native jobs are provided by the public sector. Public administration, transportation, communication, utilities, and trade account for a large proportion of this native public employment. Non-natives, however, rely basically on the private sector as a source of employment. Non-natives also account for a much larger percentage of white-collar occupations than natives, who largely are in manual and service occupations.

The personal income of Alaskans tends to vary according to racial origin and location of employment. Population categories for studying income patterns generally include non-native families, urban native families, and rural native families. The former two categories are families of high income relative to the national average, sufficient to support housing, utilities, clothing, and food necessary for adequate living conditions. Urban native and non-native families are particularly well off, and rural non-native families have shown, despite their adverse environmental and transportation problems, to be living sufficiently on incomes which support the necessities of a modern Alaskan home. Rural native family income is extremely low and accentuated by the high costs of remote transportation and goods. Large family sizes also lower the per-capita income of rural natives to an extremely low level. Subsistence acquisitions do supplement the income of these people, but do not, in fact, raise income appreciably.

IMPACT OF POPULATION AND SOCIETY ON OIL SPILL CONDITIONS

Impact of Population and Society on Oil Spill Potential

The population distribution in remote areas of Alaska often contributes to the likelihood of an oil spill. Many remote villages have inadequate or poorly maintained oil storage and transfer facilities. Neglect plus the hazards of corrosion, permafrost slump, or frost jack, may cause these facilities to rupture and leak. Fuel transfer lines are often exposed in areas where they may be damaged by moving equipment or vehicles.

Fueling facilities are also likely to be primative in remote villages. Fuel delivery is generally made by barges navigating in adjacent rivers. The barges are usually beached and connected to supply lines that are located on or under the shoreline. These lines are sometimes not well maintained and may have damaged or corroded connectors. In addition, there may be leaks between the barge and the storage tanks. The tank filling operation is monitored by someone from the village. Inattention is common and, as a result, tank over-fills are probably the most frequent cause of village spills.

Impact of Population and Society on Oil Spill Behavior

Population does not generally affect oil spill behavior except in the way that local land use may affect the way in which the oil moves after a spill has occurred.

Impact of Population and Society on Oil Spill Response

The sparsity of population in remote areas may result in a spill not being detected soon after it has occurred. Once the spill is detected, the response effort may be further hindered by a lack of available manpower, a lack of adequate spill response equipment, and a lack of training or understanding of how to take effective spill response action. In some cases there may even be a lack of motivation to respond to the spill because the potential environmental and health hazards of the spill are not understood. The State of Alaska has taken steps to educate villagers in ways to prevent oil spills and ways to respond to spills using local manpower and adapting materials that are at hand. In spite of these efforts, many locations do not have proper safeguards to prevent spills or the capability of responding to them once they have occurred.

Impact of Population and Society on Site Restoration

As in the case of oil spill response, site restoration is also likely to be adversely affected by a lack of knowledge of site restoration methods, a lack of equipment and materials, and in some cases a lack of motivation to take effective action because the hazards of leaving the spilled oil in place are not understood.

ECONOMY

The economy of the state of Alaska has been analyzed using information taken in the U.S. Census every ten years. Most economic analyses of census data are available from census data taken in 1970 and, aside from the Trans-Alaska Pipeline System construction and operation, the breakdown of industries in Alaska is not expected to have fluctuated appreciably during the 1970-1980 period. Table 4 shows the three major industries in each of the census divisions as shown in Figure 12 (15,16).

As discussed in the previous section, many rural residents of Alaska work for self support and family support rather than for profit oriented industries, which explains the fact that only a fraction of the work force is accounted for in Table 4. Also there are many smaller industries not noted among the top three in each census division. In any case, the occupations most highly impacted by oil spills are those dependent upon natural resources, such as plants and animals, for survival. Only two of the interior divisions show this type of industry in Table 4. These divisions are Cordova-McCarthy, Matanuska-Susitna, and Wrangell-Petersburg.

Commercial and subsistence employment depending upon natural resources in Alaska can be described in general terms according to geographic region (2,3,5-7). In the arctic regions north of the Brooks Range, commercial income from the land is dependent upon fur animals such as wolf, wolverine, and fox. Scattered fisheries, mainly in the Colville Delta region, harvest whitefish and cisco as well as lake trout, arctic char, and grayling. Subsistence workers depend on vegetation for small food plants, basket grass, timber for construction, and sod for housing material. Animals provide both fur and food for arctic inhabitants. These animals include wolves, wolverines, fox, caribou, owls, waterfowl, whitefish, cisco, char, chum, and pink salmon.

South of the Brooks Range commercial timber and food industries are scattered throughout the Yukon River area. Most cities established on major waterways have a fishing industry mainly catching chum and king salmon

TABLE 4. THE THREE MOST FREQUENTLY REPORTED INDUSTRIES OF EMPLOYED PERSONS FOR INLAND CENSUS DIVISIONS: 1970 CENSUS (16).

	CENSUS DIVISION	Primary Industry	Secondary Industry	Tertiary Industry
1	Anchorage	Public Admin. 18%	Construction 11%	Education 6%
2	Barrow	Misc. Profess. 22%	Education 16%	Mining 10%
3	Bethel	Public Admin. 25%	Education 17%	Hospitals 8%
4	Bristol Bay Borough	Public Admin. 40%	Education 27%	Eating & Drinking 12%
5	Bristol Bay	Education 18%	Public Admin. 11%	Other Trans. 10%
6	Cordova-McCarthy	Ag., Forest, Fish. 21%	Construction 15%	Public Admin. 9%
7	Fairbanks	Public Admin. 14%	Education 14%	Construction 12%
8	Kenai-Cook	Manufacturing 13%	Construction 15%	Mining 11%
9	Kobuk	Education 24%	Public Admin. 13%	Hospitals 12%
10	Kuskokwim	Public Admin. 39%	Non-Profit 9%	Other Pers. Serv. 8%
11	Matanuska-Susitna	Public Admin. 15%	Construction 11%	Ag., Forest, Fish. 10%
12	Nome	Education 18%	Public Admin. 17%	Other Retail 9%
13	Seward	Manufacturing 12%	Education 11%	Other Trans. 9%
14	Southeast Fairbanks	Public Admin. 23%	Construction 14%	Other Pers. Serv. 11%
15	Upper Yukon	Mining 39%	Professional 13%	Education 12%
16	Valdez-Chitina-Whittier	Construction 20%	Hospitals 13%	Public Admin. 13%
17	Wade Hampton	Education 28%	Public Admin. 12%	Non-Profit 10%
18	Yukon-Koyukuk	Public Admin. 17%	Education 16%	Other Trans. 8%

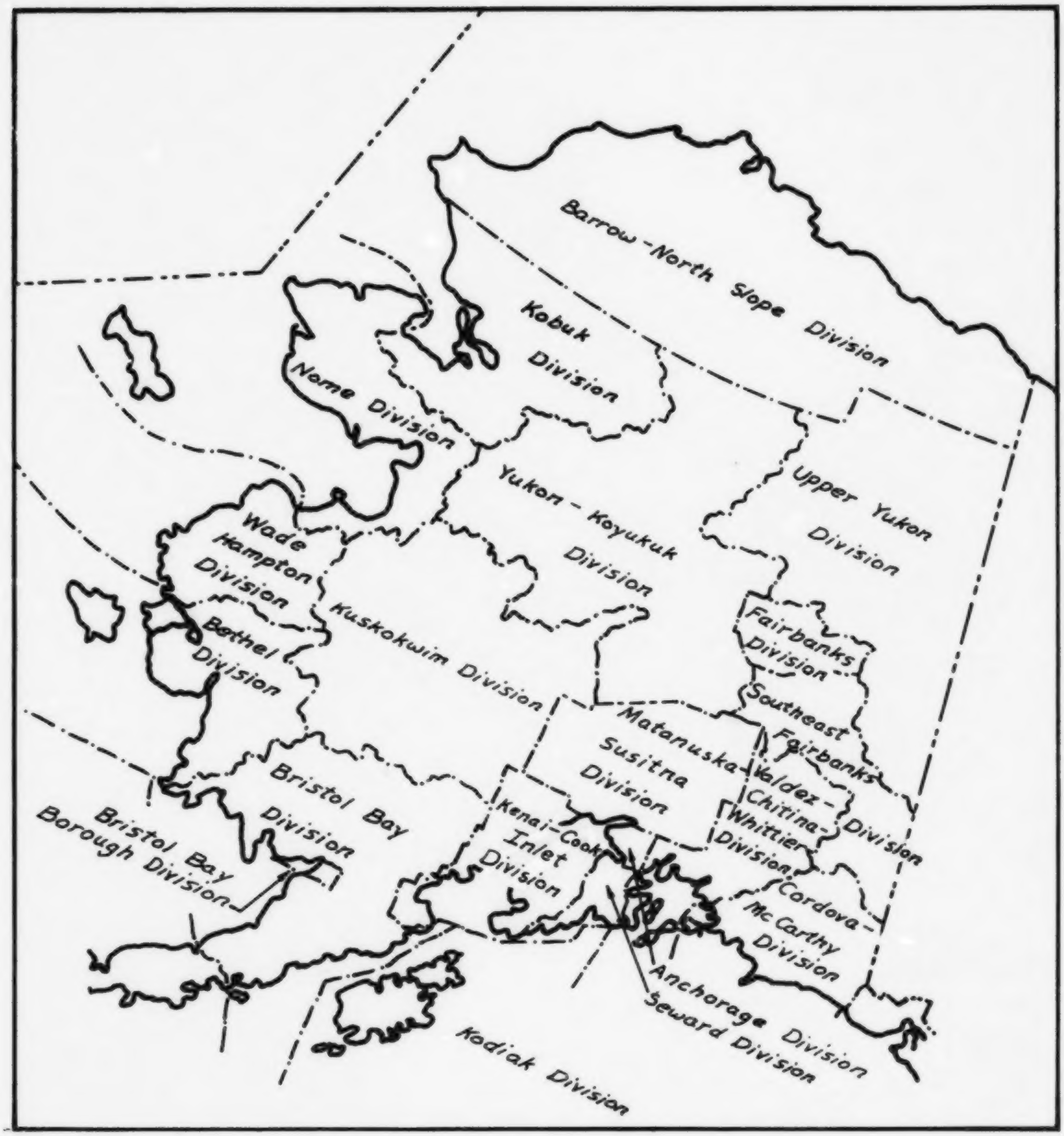

Barrow-North Slope Division
Kobuk Division
Nome Division
Upper Yukon Division
Yukon - Koyukuk Division
Wade Hampton Division
Bethel Division
Kuskokwim Division
Fairbanks Division
Southeast Fairbanks Division
Matanuska-Susitna Division
Valdez-Chitina-Whittier Division
Bristol Bay Division
Bristol Bay Borough Division
Kenai-Cook Inlet Division
Cordova-McCarthy Division
Anchorage Division
Seward Division
Kodiak Division

Figure 12. Major census divisions of Alaska.

between June 1 and September 1. Some moose are used commercially for food and clothing in the Upper Yukon, Tanana, and Porcupine River areas, and sheep are raised in the Wrangell Mountains region. Commercial use of birds and small mammals is limited by law to fur trapping of muskrat, marten, lynx, beaver, and wolf. Subsistence use of vegetables is predominantly for family food supplies, timber for housing, and grasses for baskets. Large animals such as moose, caribou, and black bear are taken for food and clothing in the interior and delta of the Yukon region. Smaller waterfowl and mammals are also hunted throughout the area for subsistence. The largest catches of fish are generally taken in the lower Yukon and upper Tanana regions and consist primarily of king salmon for human consumption and chum salmon for dog food and human consumption. Seals and walrus are used for both food and clothing on the Yukon delta.

In southcentral and southwestern areas of Alaska, the land is used for commercial farm products and timber. These areas include Cook Inlet, Bristol Bay, Kuskokwim River, Susitna River, and Copper River Basins. Grazing animals are also raised in this area. Land animals important to commercial industry are minks, bear, lynx, wolves, muskrat, wolverines, coyotes, foxes, and hare. Commercial aquatic animals include major offshore species and salmon as well as trout, char, evlachon, and whitefish. Subsistence farming and logging is also performed in this area and is supplemented with animals such as caribou, hare, grouse, waterfowl, and various types of salmon, trout, and char. Some commercial reindeer farms are located in this area.

The northwest areas of Alaska, in which the Seward Peninsula, Kobuk River, and Noatak River are situated, rely on animals for both commercial and subsistence food and fur. Fox, lynx, marten, weasel, wolverine, and many small mammals and birds are hunted continuously. Caribou, bear, sheep, and moose are taken for subsistence in this area, and reindeer are raised for commercial and subsistence use. Salmon, char, and whitefish are major aquatic animals caught by fishermen throughout the summer months. Commercial use of vegetation is mainly logging for home construction with the timber processed at small mills located at Noorvik, Elim, Council, and Kobuk. Wild berries and grasses are used for subsistence in the area.

IMPACT OF THE ECONOMY ON OIL SPILL CONDITIONS

Impact of the Economy on Oil Spill Potential

Economic conditions in some areas of Alaska may affect the possibility of an oil spill. Dependence on seasonal availability of marketable products such as fish, wildlife, and timber, or dependence on economic peaks, may lead some businesses to produce and process these products quickly and sometimes haphazardly. When these businesses use petroleum products for either manufacturing or heating, the probability of an oil spill may be greater than for more permanent businesses. Also, seasonal or high risk businesses may use equipment well beyond its normal useful life in order to minimize capital investment. The use of worn or marginally efficient equipment often increases the risk of an oil spill.

The hazards of an oil spill may also be increased in remote areas by a generally low level of cash-based economic activity and a lack of available funds. Many remote villages have virtually no tax base and no local government or comparable agency that can take action to prevent spills or to respond to spills once they have occurred. For example, the State requires that a community have a spill contingency plan if they have a fuel storage capacity of greater than 25,000 barrels. This regulation may often not be enforced until after a spill has occurred. Further, storage tanks in villages should be dyked with a berm covering a plastic liner. The State does not have the funds to inspect for these spill prevention measures in remote areas, and villages do not have the funds to install them. As a result, many villages have marginally useful fuel storage facilities with inadequate means of spill prevention.

Impact of the Economy on Oil Spill Behavior

The economy does not generally affect oil spill behavior except that patterns of land use may affect the way that the oil moves after the spill has occurred.

Impact of the Economy on Oil Spill Response

The response to a spill in a remote area will be determined by the work force available plus the availability of funds and equipment in the area. Some remote industrial worksites may be used only two to three months of the year and left unattended for the remaining months. In these cases, stored petroleum may be spilled offseason and not discovered until the new work season begins. Also in remote areas there may be a temptation to leave spills where they fall or to cover them over not recognizing the potential danger they may pose to wildlife or by leaching into streams. Although both the State and the Coast Guard may take punitive action when such spills are discovered, in many cases large or even chronic spills are not discovered until many years after they have occurred.

Impact of the Economy on Site Restoration

The economic factors that affect site restoration are similar to those that affect spill response. Site restoration is likely to be adversely affected by a lack of funds, a lack of knowledge of restoration procedures, and in some cases a lack of motivation.

TRANSPORTATION SYSTEMS

Inland Alaska is served by virtually all forms of transportation ranging from dog sled to jet aircraft. Less conventional craft such as snowmobiles, sternwheelers, canoes, and seaplanes serving as primary transportation modes are not uncommon because of the general inaccessibility of the interior regions of the state. The existence of permafrost and the low population density discourages road construction. Early freezing and late break-up limits water travel.

Figure 13 shows the major transportation network for moving people and transferring goods within the state. Each of these systems is described briefly in a paragraph that follows.

Land Transportation

Rail Transportation--

The Federal Government operates the only railroad in the state. The Alaska Railroad connects Anchorage and the Kenai Peninsula to Fairbanks. The roadbed begins at Seward and moves up the Kenai Peninsula to Anchorage. From there it follows the Susitna River to Gold Creek where it threads through the mountains near Mt. McKinley. It then follows the Nenana River into Nenana where it connects with barges serving the Yukon. The line then turns east along the Tanana River to Fairbanks and the refinery at North Pole.

Typically the railroad carries 15 to 20 carloads of refined fuels (diesel, gas, jet) each day in 38 m^3 and 75 m^3 (10,000 and 20,000 gallon) tank cars. These usually come from the North Pole refinery with fuel to be loaded onto barges at Nenana.

The total tonnage of fuels transported on the Alaska Railroad has declined in recent years, a trend that can be linked to the opening of the North Pole Refinery in 1977. Prior to that, oil had to be carried north from the Kenai Refineries. Table 5, below, shows the tonnage of fuel oil transported by the Alaska Railroad since 1971. These totals include diesel oil, home heating oil, JP-4, and commercial jet fuel.

TABLE 5. FUEL TRANSPORTED BY RAIL

This table shows annual tonnage of fuel oil transported by the Alaska Railroad during the 1970's.

YEAR	TONNAGE
1978	356,766
1977	514,835
1976	618,302
1975	548,827
1974	407,342
1973	362,577
1972	405,930
1971	247,914

In the period from 1975 to 1978, fifty-nine railroad mishaps occurred, eighteen of which were related to environmental conditions (17). Thirteen of these mishaps are possibly related to permafrost effects, three were definitely caused by permafrost slumping, one was caused by a rock slide, and one by a mudslide. Of the fifty-nine total mishaps, eight involved cars containing hazardous materials (which include petroleum products), and four resulted in spilling of the hazardous material. Two of these spills are included in the mishaps possibly related to permafrost effects. Although

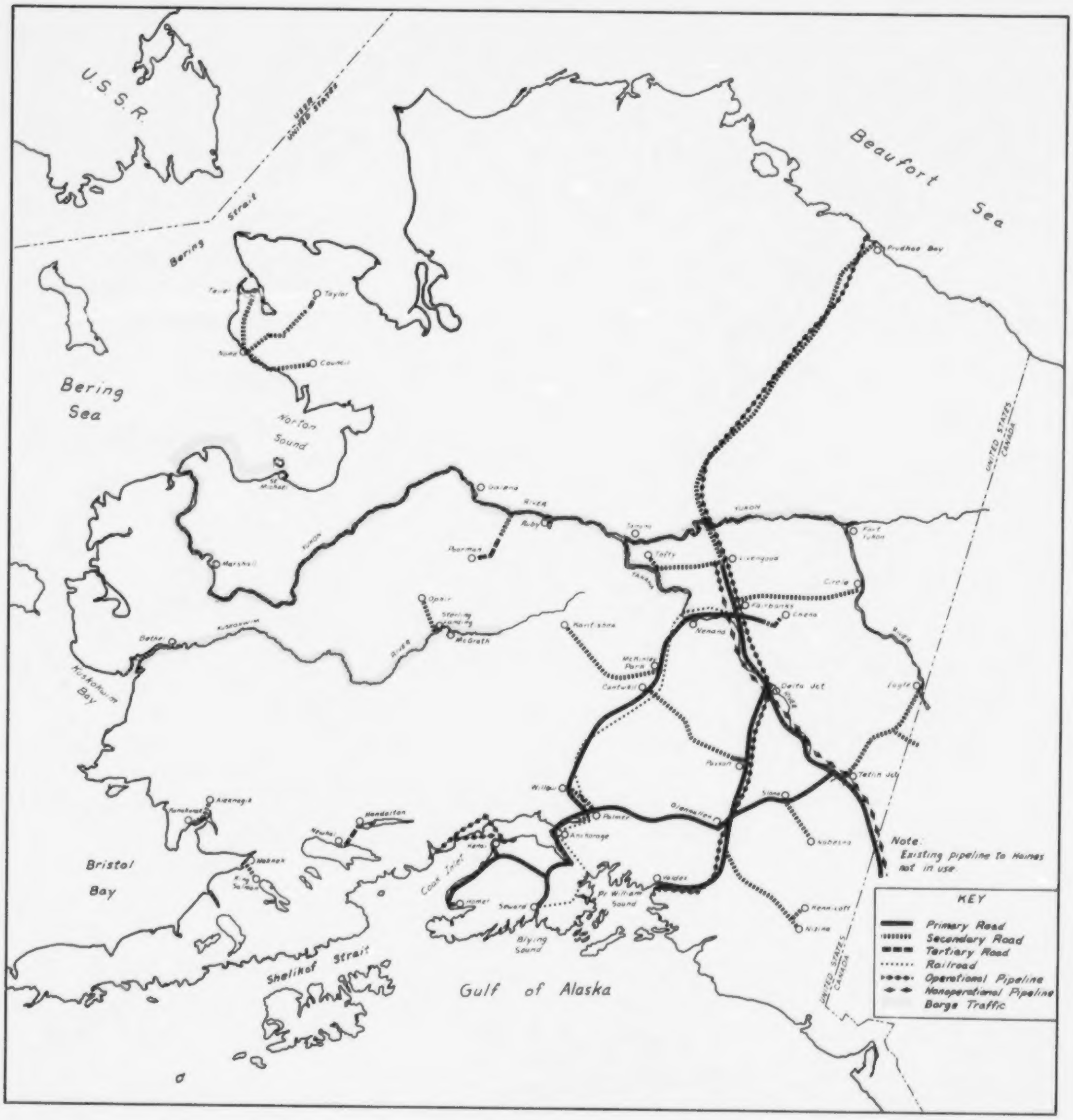

U.S.S.R.
USSR UNITED STATES
Bering Strait
Bering Sea
Taylor
Nome
Council
Norton Sound
Beaufort Sea
Prudhoe Bay
Galena
River
Ruby
Poorman
Marshall
Yukon
Tanana
Tofty
Livengood
Fort Yukon
Circle
Fairbanks
Chena
Nenana
Kantishna
Opair
Sterling Landing
McGrath
Bethel
Kuskokwim
River
Kuskokwim Bay
McKinley Park
Cantwell
Delta Jct
Eagle
Paxson
Tetlin Jct
Willow
Slana
Palmer
Glennallen
Anchorage
Nabesna
Kenai
Cook Inlet
Homer
Seward
Valdez
Pr William Sound
Blying Sound
Kennicott
Nizina
Aleknagik
Naknek
King Salmon
Newhalen
Nondalton
Bristol Bay
Shelikof Strait
Gulf of Alaska
UNITED STATES CANADA
Note:
Existing pipeline to Haines not in use
KEY
Primary Road
Secondary Road
Tertiary Road
Railroad
Operational Pipeline
Nonoperational Pipeline
Barge Traffic

Figure 13. Major transportation networks in Alaska.

these may not be considered an unusual number of mishaps considering the natural hazards of the environment, there remains at least a moderate threat of oil spill situations resulting from rail accidents.

Roadway Transportation--

Relatively few highways exist in Alaska and most are clustered south of Fairbanks and east of Anchorage. These roads join with the ALCAN highway to connect Alaska with the lower 48. Generally the roads are built to primary standards and open year-round. The Denali Highway and the Taylor Highway are closed by snow in the winter but are generally passable with four wheel drive vehicles.

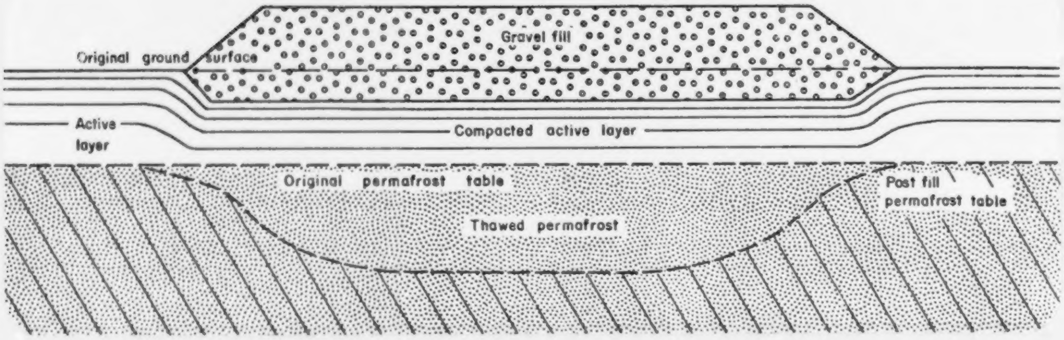
The Haul Road, originally built for the pipeline to connect Livengood to Purdhoe Bay, has recently been opened to the public. The road is built to secondary highway standards. Travel on the road is best during the winter once the snow has been plowed. High winds cause considerable drifting on the road requiring continual plowing. In the spring the road bed becomes soft and collapses in some places. Reduced loads and speeds are recommended during this time.

Other short local roads exist throughout the state. These roads are generally unimproved and connect an airstrip with a community or a mining area with a river. Freight is not generally delivered to the interior communities by truck. In most cases, supplies must be delivered by barge or by air.

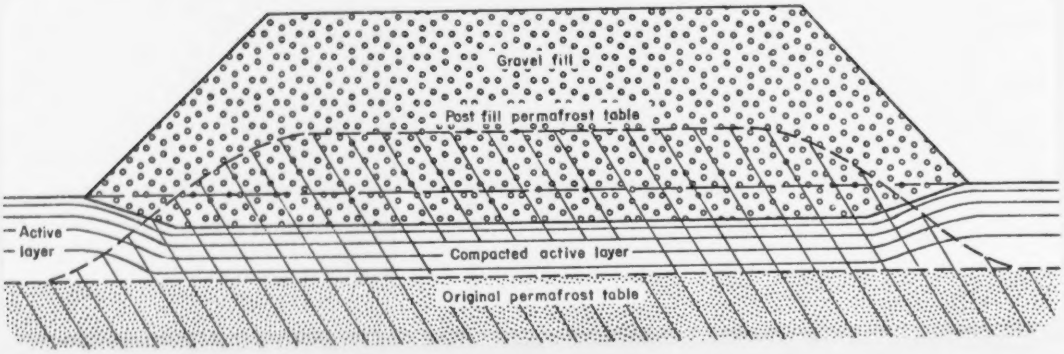
Motor freight, including petroleum tank trucks, travels daily from Anchorage and Seward or Valdez to Fairbanks. During the spring season load restrictions are placed on even the major paved roads. Generally loads must be reduced to 75% of axle weight and speeds reduced to 55 kph. In particularly sensitive areas, the restrictions are further reduced to 50% of axle weight. Vehicle sizes are limited to a maximum of 2.5 m x 21 m (8 ft x 70 ft). In emergency situations, such as an oil spill response effort, these restrictions would be waived.

Road construction requires special procedures in Alaska. The presence of permafrost throughout the state means that any roads built require insulating foundations to preserve the frozen soil structure and avoid major collapse of the road. Figure 14 shows the thawing effect on the permafrost layer if normal road bed design is used. The thin gravel layer is insufficient to insulate the permafrost and a gradual slumping of the road will occur. Constructing the road with a thick gravel layer allows the permafrost to reform and grow up into the road bed, forming a stable foundation (6).

Surface transport is also limited in Alaska by the fact that offroad travel is generally restricted to the winter months. The state prohibits all offroad activity north of the Brooks Range from mid-May to mid-July. Vehicles attempting to operate offroad during this time would find surface soils very soft or unsupported. Erosion of the surface soil would be easy, destroying the natural insulation provided by the active soil layer. Major slumping of the ground would begin as the exposed permafrost begins to thaw.


Gravel fill
Original ground surface
Active layer
Compacted active layer
Original permafrost table
Post fill permafrost table
Thawed permafrost

a. Depressed permafrost table due to insufficient gravel insulation resulting in slumping.


Gravel fill
Post fill permafrost table
Active layer
Compacted active layer
Original permafrost table

b. Stable permafrost table with adequate gravel insulation.

Figure 14. Design considerations for road construction over permafrost.

Rolligon movement on the tundra is permitted after July 15 until a stable snow cover is formed in the fall. Both tracked and wheeled vehicles can then operate until breakup. Any offroad activity on the North Slope must first be approved by the Alaska Department of Minerals and Energy Management. South of the Brooks Range approval for offroad activities must be granted by BLM and the appropriate Native Regional Corporation. As a blanket policy, BLM prohibits any offroad activity, regardless of the situation, during the summer season. Rolligon use is permitted once a 15 to 25 cm snow cover has been established.

Pipelines--

Pipelines in Alaska serve to transfer oil from production fields and to distribute heating oil from community storage tanks. Foremost among these is the Trans-Alaska Pipeline, taking oil gathered from the wells at Prudhoe Bay and carrying it to a tanker terminal at Valdez. The 1290 km (800 mile) pipeline crosses the treeless tundra of the North Slope, ascends the Brooks Range, descends into Alaska's northern interior and into the rolling hills north of the Yukon River. Farther south the pipeline passes near Fairbanks then climbs over the Alaska Range and Chugach Range before dropping to sea level at Valdez. The 48 inch pipeline is underlain by permafrost over virtually the entire route. More than half of the pipeline is elevated and the rest is buried. Elevated sections range from about 50 km to a hundred meters in length. The raised portion minimizes problems with thermal cracking, permafrost degradation, and difficult excavation. The buried sections are more aesthetically desirable and provide places for egress to certain animal movements and migration. Some buried sections require refrigeration to prevent the permafrost from melting (5).

The present capacity of the Trans-Alaska Pipeline (TAPS) is 1.16 million barrels of oil per day using eight pumping stations. At full capacity, 2 million barrels of oil per day can be pumped using twelve pumping stations. At any time the pipeline contains 9 million barrels of oil. A total of 151 gate and check valves protect the environment from possible spillage by limiting the volume that can be spilled (18).

An eight and six inch gas pipeline carries gas from Prudhoe Bay to pumping stations north of the Brooks Range to operate pumps. Small topping plants at stations south of the Brooks Range produce kerosene from the crude in the pipeline to keep their pumps in operation.

The Haines-Fairbanks pipeline was constructed in 1955 to deliver fuel to military installations around Fairbanks. The eight inch pipeline is buried between Fairbanks and Delta Junction, and is raised from Delta Junction to Haines. The pipeline has had a history of spills dating to the time of its opening. For environmental reasons and decreased strategic importance, most of the pipeline was shutdown in 1972. Only a 43 km stretch between Ft. Wainwright and Eielson AFB is still in use. Prior to the construction of TAPS, it was the only major pipeline in the subarctic traversing a variety of vegetation and soil types, and had construction both above and below the ground. With its history of spills it serves as the basis of study of environmental impact due to pipeline oil spills and appropriate types of site restoration (19).

The fields of Cook Inlet produce both gas and oil. The oil is processed at refineries at Kenai and Drift River or loaded into tankers. Gas produced by the fields is either loaded into LNG tanks or transferred through a 12 inch pipeline directly to the Anchorage community. Additionally, an eight inch pipeline connects the ice-free port of Whittier to Elmendorf AFB (6).

Elsewhere in the state small pipelines run from riverbanks or docks to fuel storage tanks onshore. These lines are used to refill a small village communal storage tank with heating oil from a barge. The longest run of pipe used for tank refill is approximately 2.4 km and requires added onshore pumping capacity. Oil is then transferred to the home from the tank through small, individual pipelines.

Impact of Land Transportation Systems on Oil Spill Conditions

Impact of Transportation Systems on Oil Spill Potential--

The extremes in environmental conditions throughout Alaska increase the potential for a land transportation related spill. Thawing permafrost can result in collapse of a highway or railroad bed causing vehicular oil spillage. Slumping of ground can also cause distortions in the pipeline which could lead to cracking.

Impact of Transportation Systems on Oil Spill Behavior--

Many of the existing roads tend to parallel stream beds and often criss-cross the streams. Spills due to truck, train, or pipeline accidents would generally drain into this water system. Buried pipelines could leak into the soil, follow the groundwater table, and emerge some distance from the source. Above ground spills from truck, train, or pipeline would locally kill vegetation.

Impact of Transportation Systems on Oil Spill Response--

The lack of a major roadway system makes vehicular response to a remote spill limited. Vehicles or machinery needed in a cleanup effort would have to be flown into an area, delivered by barge, or in the case of a railroad spill, brought in by train. Even when access by road is possible, considerable offroad activity would be required. The soft active layer of the soil will bog down most wheeled vehicles. Environmental considerations will further limit the type and level of offroad activities permitted.

Impact of Transportation Systems on Site Restoration--

Site restoration will be hampered by the same kind of problems as the spill response. In addition, the site restoration may include a much larger area than the immediate spill site due to vehicular damage done to the environment during the cleanup effort.

Marine Transportation

Inland Alaska is served by barge on the two major river systems, the Yukon River and the Kuskokwim River. The majority of the traffic is on the Yukon and is handled by the Yutana Barge lines and Black Navigation. Yutana barges originate from Nenana, on the Tanana River, a major tributary of the Yukon. Although all kinds of dry cargo are carried on the deck of the barges, petroleum products are the principal cargo. Diesel, gasoline, JP-4, and A50 stove oil are carried by rail and tank cars from the refinery located at the North Pole, just outside of Fairbanks, to the loading pier at Nenana. The petroleum is loaded into barges that are pushed in pairs by a tugboat to destinations up and down river. Due to draft restrictions, typically no more than 757 m^3 (200,000 gallons) of fuel are carried on each voyage. The barges transport the oil as far west as Marshall, with regular shipments to Galena, and as far east as Fort Yukon. The round trip to Marshall, 1245 km (774 miles) downstream from Nenana, takes from 17 to 25 days.

The operating season generally begins two weeks after ice breakup, roughly mid-May, and is terminated October 1, to avoid becoming frozen into the ice. Currents in the river typically run 6 knots and even higher during spring runoff. The channel is constantly changing and must be continually sounded on each voyage. However, the river is very wide with few dangerous obstructions. Near Rampart the current runs as fast as 12 knots over large boulders. Fortunately, a well known, stable channel exists in this area so that there is little chance of collision with the rocks.

Coastal communities of Norton Sound and communities on the Yukon Delta are served by Black Navigation, also run by Yutana Barge. Because of the extensive offshore shoals, barges must be loaded from larger ships or onshore tanks at St. Michaels on the coast. The oil is then brought upriver as far as Marshall or along the coast of Norton Sound to the small communities in the area.

Most of the villages along the Yukon River have no piers or docking facilities to support the barge deliveries. Of all the stops made on the Yukon, only Ft. Yukon and Galena have piers provided by commercial petroleum distribution companies. At other locations the barges are beached on the river banks, secured to special or temporary pilings, and the products are pumped directly to the customer, generally either the village storage tank or a BIA school. The highest potential for an oil spill occurs during the delivery process. Village transfer lines are generally simply laid out on the ground to the transfer point. Since these lines are exposed in all seasons, they may deteriorate and rupture or may leak at connecting points. Sometimes the lines may become buried by sediments on the river bank and crews must dig to find the delivery junction. The products are generally pumped ashore by the barges, however, if the receiving tank is a great distance from the river, booster pumps are required. One village on the Yukon has the receiving tanks 2.4 km (1.5 miles) from the river. Tank overfill caused by operator inattention or equipment malfunction is the most frequent source of spills in barge delivery operations.

The safety and operation of the barges comes under the jurisdiction of the Coast Guard. However, responsibility for the cleanup of spilled oil falls under EPA authority.

Barge traffic on the Kuskokwim River is about the same as that on the Yukon. Two barge companies, United Transportation and M&K Freight, service the area from Bethel. Between the two firms, there are three petroleum barges, the largest of which has a capacity of 35 m^3 (93,000 gallons). The barges travel up river from Bethel to 65 miles above McGrath. The start and close of the operating season occurs about one week earlier than on the Yukon.

Impact of Marine Transportation on Oil Spill Conditions

Impact of Marine Transportation on Oil Spill Potential--

Even with the fast moving currents of the Alaska Rivers, the danger of an oil spill due to a barge casualty is considered small because of the great width of the river and the soft bottom material. A marine spill is most likely to occur at the remote villages or schools where a small spill might occur from leaking lines, bad valves, or tank overfill. Also, loaded barges caught in an early freezeup could rupture from the force of the ice and cause a spill.

Impact of Marine Transportation on Oil Spill Behavior--

Oil spilled on an Alaskan river would probably be swept away immediately due to the fast currents. If tributaries or quiet pools occur downstream, some of the oil might become caught in these quiescent zones and begin to accumulate. The highly volatile oils carried by the barge could evaporate fairly rapidly on the water surface.

Impact of Marine Transportation on Oil Spill Response--

Swift currents and moving debris will hamper any cleanup effort. Response equipment could be carried on the barge, flown in, or brought by another boat; however, much of the river will be inaccessible for timely response. Vegetation and soft river banks may make cleanup from onshore difficult.

Impact of Marine Transportation on Site Restoration--

Vegetation killed due to the spill may cause additional erosion of the river banks. Site restoration may be adversely affected by continual eroding and flooding of areas to be re-established.

Air Transportation

Although many small villages are inaccessible to land or river transportation in the winter, a great many have landing fields and can be reached by air when weather conditions are favorable. Some small villages have relatively well developed airport facilities (20). For example, St. Mary's, on the Yukon River, has a 6000 foot hard surface runway, an Instrument Landing System (ILS), a low frequency radio beacon, and Distance Measuring Equipment (DME). This facility would be capable of handling a C-130 Hercules, an Electra, a DC-6, or even a Boeing 727 in weather conditions down to a ceiling of about 200 feet and visibility of 1/2 mile. On the other hand, some small villages have a landing strip but they are not equipped to handle large aircraft or any aircraft in instrument flight conditions (IFR). St. Michaels is a small town on the western coast that serves as a port at the mouth of the Yukon. This village, in contrast to St. Mary's, has an unpaved runway that is only 1975 feet long and is 43 nautical miles from the nearest aid to navigation. This airport can only serve the smallest aircraft in clear weather. Thus there are wide differences in airport facilities among small villages.

Air travel is very common in Alaska, and well developed air facilities in some locations provide an unusual level of accessibility in areas that are extremely remote to any other means of travel. The severe climate of Alaska also imposes restrictions on flight operations. Some of the problems in flying include adverse weather, darkness, poor runway and landing strip conditions, limited availability of alternate airfields, limited availability of adequate air navigation systems, limited availability of fuel, adequate ground support, and the general problem of operating aircraft in extremely cold ambient temperatures. Even well developed fields with advanced aids to navigation can be expected to be closed to aircraft for days at a time because of adverse weather conditions.

Table 6 shows the runways in Alaska that are 3000 feet or longer (21). Although there are a great many runways that fall into this category, many do not operate in all seasons and many are for daylight, visual operations only. Table 7 shows a representative list of aircraft that could be expected to operate from these airfields and helicopters that generally do not require the support of airfields. There are many relatively large aircraft that are capable of operating at the available airfields. For example, the C-130 Hercules is an aircraft with a large carrying capacity and capable of operating from a 4000 foot runway. The DC-3 is still operating in Alaska and can use a runway of about 3000 feet. The Twin Otter is used extensively in remote areas and can use runways of only 1000 feet. Of course the aircraft using the shorter runways generally have a small payload and could not be expected to support a large spill response operation.

Many older DC-3 aircraft have been configured as fuel tankers to supply remote villages that may run out of heating fuel in the winter. Accidents involving these aircraft could also be the cause of spill situations in remote areas (22).

In some cases aircraft equipped with skis can land on snow or ice in remote areas. These operations cannot be considered as independent but rather can only occur when there is contact with the ground so that the proposed landing site can be inspected and found to be safe for landing.

Impact of Air Transportation on Oil Spill Conditions

Air transportation does not generally have an impact on oil spill conditions except in a few special cases. For this reason, the potential will only be treated here in a very general way.

Alaska has a great many airports, or, in some cases, remote landing fields. These landing facilities are often located adjacent to inland rivers and, as a result, there is a potential impact on waterways from spills that occur at airports. Aircraft servicing may cause small, periodic spills or

TABLE 6. LARGER AIRPORTS IN ALASKA

Aerodrome	Nearest City or Town	Longest Runway (ft)*	Fuel Available	Runway Lighting		Radio Aids To Navigation		Comments
				Yes	No	Yes	No	
Adak NS	Adak	7,800	Avgas JP-5	X		X		Year-round
Allen, AAF	Fort Greely	7,500	Avgas JP-4	X		X		Year-round
Anaktuvuk Pass	None	4,400	None		X		X	Unattended
Anchorage Intl.	Anchorage	10,900	All types	X		X		Year-round
Aniak	None	5,000	Avgas	X		X		Attended daylight only
Annette Island	Ketchikan	7,500	Avgas, Jet fuel	X		X		Year-round
Barter Island DEW Sta.	-	4,800	Jet fuel	X		X		Attended daylight hours
Beaver	-	4,100	None		X		X	Unattended
Beluga	Tyonek	5,000	None	X			X	Year-round
Bethel	Bethel	6,400	Avgas, Jet fuel	X		X		Year-round
Bettles	-	5,200	Avgas, Jet fuel	X		X		Year-round
Big Mountain AFS	-	4,200	None	X		X		Year-round
Birchwood	Anchorage	4,000	Avgas	X			X	Attended daylight hours
Bob Baker Mem	Kotzebue	4,000	Avgas		X		X	Unattended
Campbell Airstrip	Anchorage	5,000	None		X		X	Unattended; skis only in winter
Cape Lisburne AFS	-	5,000	None	X		X		Daylight operations only
Cape Newenham AFS	-	4,100	None	X		X		Daylight operations only
Cape Romanzof AFS	-	4,000	None		X	X		Daylight operations only
Cape Sarichef AFS	-	3,500	None	X		X		
Casco Cove CGS	Attu	6,000	None	X			X	
Chaix Hills	Icy Bay	4,200	None		X		X	Unattended
Chandlar Lake	-	4,500	None		X	X		Unattended
Chisana	-	4,200	None		X		X	
Circle Hot Springs	-	4,000	Avgas	X			X	Unattended
Clear MEWS	Nenana -	4,000	None	X			X	Operation only at reduced weight
Coal Creek	-	4,000	None		X		X	Unattended
Cold Bay	-	10,100	Avgas, Jet fuel	X		X		Year-round
Cordova Mile 13	Cordova	7,500	Avgas	X		X		Year-round
Dahl Creek	Kobuk	3,900	None		X		X	Unattended
Deadhorse	Prudhoe Bay	5,000	Avgas, Jet fuel	X		X		Year-round
Dillingham	-	4,800	Avgas	X		X		Year-round
Drift River	-	4,300	None	X			X	Year-round
Driftwood Bay AFS	-	3,500	None	X		X		On Unalaska Island
Dutch Harbor	-	4,300	Avgas		X		X	
East Fork	Prudhoe Bay	6,000	None	X			X	Unattended
Eielson AFB	Fairbanks	14,500	Avgas, JP-4	X		X		Year-round
Elmendorf AFB	Anchorage	10,000	Avgas, JP-4	X		X		Year-round
Fairbanks Intl.	Fairbanks	10,300	All types	X		X		Year-round
Farewell	-	5,000	None	X		X		Year-round
Flat	-	4,100	Avgas		X		X	Unattended
Fort Yukon	-	5,000	Avgas, Jet fuel	X		X		Year-round
Galena	-	6,600	Avgas, JP-4	X		X		Year-round
Gambell	-	4,500	None	X			X	Unattended St. Lawrence Island
Goose Bay AAF	Anchorage	5,000	None	X			X	Unattended

* Current aviation practice lists runway lenghts in English units of feet.

TABLE 6. (Continued)

Granite Mtn AFS	-	3,900	None	X		X		
Gulkana	Glenallen	4,200	Avgas, Jet fuel	X		X		Attended daylight hours
Gustavus	-	7,500	None	X		X		No winter maintenance
Haines	-	4,600	Avgas		X	X		Unattended
Hog River	-	4,000	None		X		X	Unattended
Homer	-	7,400	Avgas	X		X		Year-round
Hooper Bay	-	4,000	None	X			X	Unattended, weight restriction
Hughes	-	4,600	None		X		X	Attended daylight only
Illiamna	-	5,000	Avgas	X		X		Year-round
Indian Mtn AFS	-	4,100	None	X		X		Daylight operations only
Jensens	-	4,700	None		X		X	Unattended
Juneau Muni.	Juneau	8,400	Avgas, Jet fuel	X		X		Year-round
Kad River	-	5,400	None		X		X	Unattended
Kalakaket Creek AFS	-	4,000	None	X		X		
Kavik River	-	5,900	None	X		X		
Kenai Muni.	Kenai	7,500	Avgas, Jet fuel JP-4	X		X		Year-round
Ketchikan Intl.	Ketchikan	7,500	Avgas, Jet fuel	X		X		Year-round
King Cove	Cold Bay	4,000	None		X		X	Unattended, no facilities
King Salmon	-	8,500	Avgas, Jet fuel JP-4	X		X		Year-round
Kodiak	Kodiak	7,500	JP-4	X		X		Year-round
Kulik Lake	-	4,600	Avgas		X		X	Attended May-Sept., Daylight only
Lonely DEW Station	-	3,800	None	X		X		
May Creek	McCarthy	4,300	None		X		X	Unattended
McGrath	-	5,600	Avgas, Jet fuel	X		X		Year-round
Merrill Field	Anchorage	4,000	Avgas, JP-4	X		X		Year-round
Metro Field	Fairbanks	4,600	Avgas		X		X	Attended daylight
Middleton Island	-	5,100	None	X		X		Unattended, soft in spring
Minchumina	-	4,600	None		X	X		Not maintained
Moses Point	-	4,600	None		X	X		Unattended
Mt. Mckinley Natl. Park	-	5,000	None		X		X	Unattended
Nenana Muni.	Nenana	6,200	Avgas, Jet fuel	X		X		
Nikolai Creek	Tyonek	4,100	None		X		X	Unattended
Nikolski AFS	-	3,500	None	X		X		On Umnak Island
Nome	Nome	6,000	Avgas, Jet fuel, JP-4	X		X		Year-round
Northeast Cape AFS	-	5,000	None	X		X		On St. Lawrence Island, Daylight operation
North Shore	-	8,400	None		X		X	Unattended, Umnak Island
Northway	-	4,300	Avgas, JP-4	X		X		Year-round
Oliktok DEW Sta.	-	4,000	None	X		X		
Painter Creek 1	-	5,000	None		X		X	Unattended
Petersburg	Petersburg	4,600	Avgas	X		X		Unattended
Pingo	Prudhoe Bay	6,000	None	X			X	Unattended, not maintained
Platinum	-	4,000	Avgas	X		X		Unattended, dangerous when wet

TABLE 6. (Continued)

Point Barrow NARL	Barrow	5,000	Avgas, Jet fuel	X		X		
Point Hope	-	4,100	Avgas	X			X	Unattended
Point Lay DEW Sta.	-	3,500	None	X		X		
Port Clarence CGS	-	4,500	Avgas	X		X		
Port Heiden	-	7,500	Avgas	X		X		Unattended; soft when wet
Port Moller AFS	-	3,500	None	X		X		
Prudhoe Bay	-	5,500	None	X		X		
Ralph Calhoun Mem.	Tanana	4,400	Avgas	X		X		
Ralph Wien Mem.	Kotzebue	5,900	Avgas, kerosene	X		X		Year-round
Red Devil	-	4,000	Avgas		X		X	Unattended; runway soft
Sagwon	-	5,800	Avgas, Jet fuel		X		X	
St. Marys	-	6,000	None	X		X		
St. Paul Island	-	5,100	None	X		X		Unattended
Sand Point	-	3,800	Avgas		X		X	Unattended; on Popof Is.
Sandy River Federal 1	Port Moller	4,000	None		X		X	Unattended; not maintained
Savoonga	-	4,000	None	X			X	St. Lawrence Island
Seward	Seward	4,700	Avgas	X			X	Attended daylight
Shemya AFB	Atka	10,000	Avgas, JP-4	X		X		Year-round
Sitka	Sitka	5,000	Avgas, Jet fuel	X		X		Year-round
Sitkinak CGS	-	4,500	None	X		X		
Soldotna	Soldotna	5,000	Avgas	X		X		Year-round
South Naknek No. 2	King Salmon	3,600	None	X			X	Unattended
Sparrevohn AFS	-	4,100	None	X		X		Daylight operations only
Stampede	-	4,300	None		X		X	Unattended
Summit	-	5,000	None	X		X		Unattended
Talkeetna	-	4,000	Avgas, Jet fuel	X		X		
Tanacross	-	5,100	None		X		X	Unattended
Tatalina AFS	-	3,800	None	X			X	Daylight operations only
Tin City AFS	-	4,700	None	X		X		Daylight operations only
Trading Bay Production	-	4,500	Avgas	X			X	
Umiat	Umiat	5,400	Avgas	X			X	Unattended; maintenance discontinued
Unmak	-	8,100	Avgas	X		X		Unattended
Unalakleet	-	6,000	Avgas	X		X		No winter maintenance
Upper Hannum Creek	-	4,000	None		X		X	Unattended
Valdez 2	Valdez	4,400	Avgas, Jet fuel		X		X	Unattended
Wainwright AAF	Fairbanks	8,700	JP-4	X		X		Year-round
Wainwright DEW Sta.	-	3,500	None	X		X		
West Kavik	-	5,200	None		X		X	
West Kuparuk	Prudhoe Bay	5,000		X			X	Unattended; not maintained
Wien Arctic Village	Arctic Village	4,400	None		X		X	Unattended
W. Post/ W. Rogers Mem.	Barrow	6,500	None	X		X		Year-round
Wrangell	Wrangell	5,000	Avgas		X	X		Daylight only
Yakatanga	-	4,900	None		X	X		Unattended; daylight only
Yakutat	Yakutat	7,800	Avgas, Jet fuel	X		X		Year-round

TABLE 7A. AIRCRAFT CHARACTERISTICS--FIXED WING (22).

Name	Model	Fuel						Runway Requirements*								Landing Gear Options			Freight **		
								Normal				Emergency									
		80/87	100/130	115/145	JP1	JP4	JP5	Paved	Gravel	Snow/Ice	Water	Paved	Gravel	Snow/Ice	Water	Wheels	Floats	Skis	Door Size (in)	Maximum Package Size (in)	Disposable Weight (lbs)
HEAVY TRANSPORT																					
Boeing 727	QC				X	X		6,000	6,000	6,000		5,000	5,000	5,000		X			134x91	290x119x 55	71,221
Boeing 737	200				X	X		9,000	9,000			6,000	6,000			X			134x86	154x 55x 83	56,000
Douglas DC6	AB		X	X				5,000	5,000	5,000		4,500	4,500	4,500		X			124x78	106x 86x 80 51x 10x140	39,500
Lockheed Electra	L-188C				X	X		5,000	5,000	5,000		3,600	3,600	3,600		X			140x78	51x 40x 80 780x 32x 6	45,500
Lockheed Hercules	L-100-30				X	X		5,000	5,000	5,000		4,000	4,000	4,000		X			120x108	51x 40x 30 552x114x103	81,435
MEDIUM TRANSPORT																					
De Havilland Buffalo	DHC5				X	X		3,000	3,000	3,000		1,500	1,500	1,500		X			92x82	420x 72x 40	16,000
Douglas DC3			X					3,400	3,400	5,000		2,500	2,500	3,500		X		X	84x70Front 84x55Rear	48x 56x117 24x 24x357	7,400Wheels 6,400Skiis
Fairchild (Fokker)	F27, F227				X	X		4,000	4,000			3,500	3,500						90x70	216x 36x 24	17,500
LIGHT TRANSPORT																					
Beechcraft	G-18	X	X					2,500	2,500	2,500		1,500	1,500	1,500		X			60x38	96x 18x 24	3,900
Cessna	180,185		X					1,500	1,500	2,000	3,000	1,500	1,500	2,000	3,000	X	X	X	38x39	78x 20x 30	1,400
Cessna	337G		X					3,500	3,500	3,500		1,800	2,000	2,000		X			40x37	38x 35x 18	1,570
Cessna	402,421		X					3,500	3,500	3,500		2,500	2,500	2,500		X			36x42	28x 34x 34	2,250
De Havilland Beaver	DHC-2	X	X					1,500	1,500	2,000	3,000	900	900	1,500	2,500	X	X	X	40x40	36x 23x 23	1,730
De Havilland Otter	DHC-3	X	X					1,500	1,500	2,500	3,000	800	800	1,500	2,500	X	X	X	46x45	76x 24x 4 46x 46x 40	2,600
De Havilland Twin Otter	DHC6-300				X	X	X	2,200	2,200	2,500	3,500	1,000	1,000	1,500	3,000	X	X	X	56x50	130x 18x 24 52x 48x 49	5,000
Short Skyvan	SC-7				X	X		2,200	2,200	2,200		1,500	1,500	1,500		X			78x78	215x 49x 8 74x 78x 80 223x 72x 60	5,000

* Current aviation practice lists runway lengths in English units of feet.

** According to current practice, aircraft characteristics are given in English units.

TABLE 7B AIRCRAFT CHARACTERISTICS -- HELICOPTER (22)

Name	Model	Fuel						Landing Gear Options				Freight*		
		80/ 87	100/ 130	115/ 145	JP1	JP4	JP5	Wheels	Floats	Skis	Skids	Door Size (in)	Maximum Package Size (in)	Disposable Weight (lbs)
HEAVY TRANSPORT														
Boeing Vertol	CH113				X	X		X				72x72	70x68x160	9,400
Sikorsky	S61L					X	X	X	X			47x64	64x38x 72 360x 6x 6	8,150
Boeing Vertol Chinook	CH147				X	X	X	X	X	X		90x78	366x89x 77	26,000
MEDIUM TRANSPORT														
Bell 205/204	A-1				X	X	X		X		X	90x49	90x90x 48 132x24x 24	3,512
Bell 212	CH-135				X	X			X		X	90x49	90x90x 80 132x24x 24	4,459
Sikorsky	S-58T				X	X		X				52x48	48x48x 48	5,300
Sikorsky Sea King	CH-124					X		X	X			68x60	360x 6x 6 64x58x 48	5,800
LIGHT TRANSPORT														
Bell 47 Series	G2, G3, G4	X	X						X		X	External Racks		900
Bell 206 Jet Ranger	CH-136					X			X		X	35x36	45x36x 34	1,259
Hughes	500-D				X	X			X		X	30x38		1,380
Sikorsky	S-55T				X	X	X	X	X			78x46	46x44x 38	2,700

* According to current practice, aircraft characteristics are given in English units.

may result in fairly large spills in servicing storage tanks or in the case of tank leaks. Aircraft ground support operations do have a fairly high potential for causing spills and in many cases these spills may threaten adjacent inland waters.

Aircraft are often used as tankers for fuel. If a remote village runs out of fuel oil in the winter, or if it had not been adequately serviced by barge in the summer, fuel transport by aircraft is likely to be required. Accidents may result from this use of aircraft and could cause a spill in a remote area. In many areas of Alaska it may be difficult to rescue the survivors of such an accident and the area may be so remote that a spill response effort would not be possible. As a result, air transportation operations may result in spills in remote areas of high environmental sensitivity, but in an area where a spill response effort could not be mounted.

PETROLEUM DEVELOPMENT

Current Production

Presently, there are three regions of Alaska producing petroleum products: Cook Inlet, producing both gas and oil; Barrow, producing gas; and Prudhoe Bay, producing gas and oil. Cook Inlet and Prudhoe Bay, the oil producing areas, yielded nearly 72 million m^3 (450 million barrels) of oil in 1978, with Prudhoe accounting for 89% of this total. Figure 15 illustrates the areas of petroleum productivity in Alaska (23).

Exploration and Resource Potential

Exploratory drilling is continuing in scattered areas throughout the state, with much of this activity occurring in the National Petroleum Reserve-Alaska (NPRA). During the winter of 1978-79, test wells were sunk in NPRA on the coastal plain near Umiat, and in the southern part of the reserve near its north-south meridian. The 1979-80 season plans are to drill in the center of the reserve area and also along an arc 100 km south of Barrow.

Regions with potential oil reserves are identified in Figure 15. A tentative five year lease schedule for exploration is given in Table 8 covering many of the reserve areas (24).

The Copper River Basin Area shows discovery potential as low to moderate. Although natural oil seeps occur in the area, wells drilled to the west of the sale area have made no significant discoveries. The area is considered to have a low environmental sensitivity and risk (25).

The Beaufort area shows the highest probability for petroleum potential. A number of promising wells have been drilled on adjacent tracts, including the Prudhoe Bay discovery well. Exploration will be limited to areas with low risk of environmental damage. Extremely sensitive or high risk areas such as pack ice areas have been deleted from the sale. Because of the harsh conditions, remote location, and environmental sensitivity, and given the season limitations on operations in the region, ten years can be

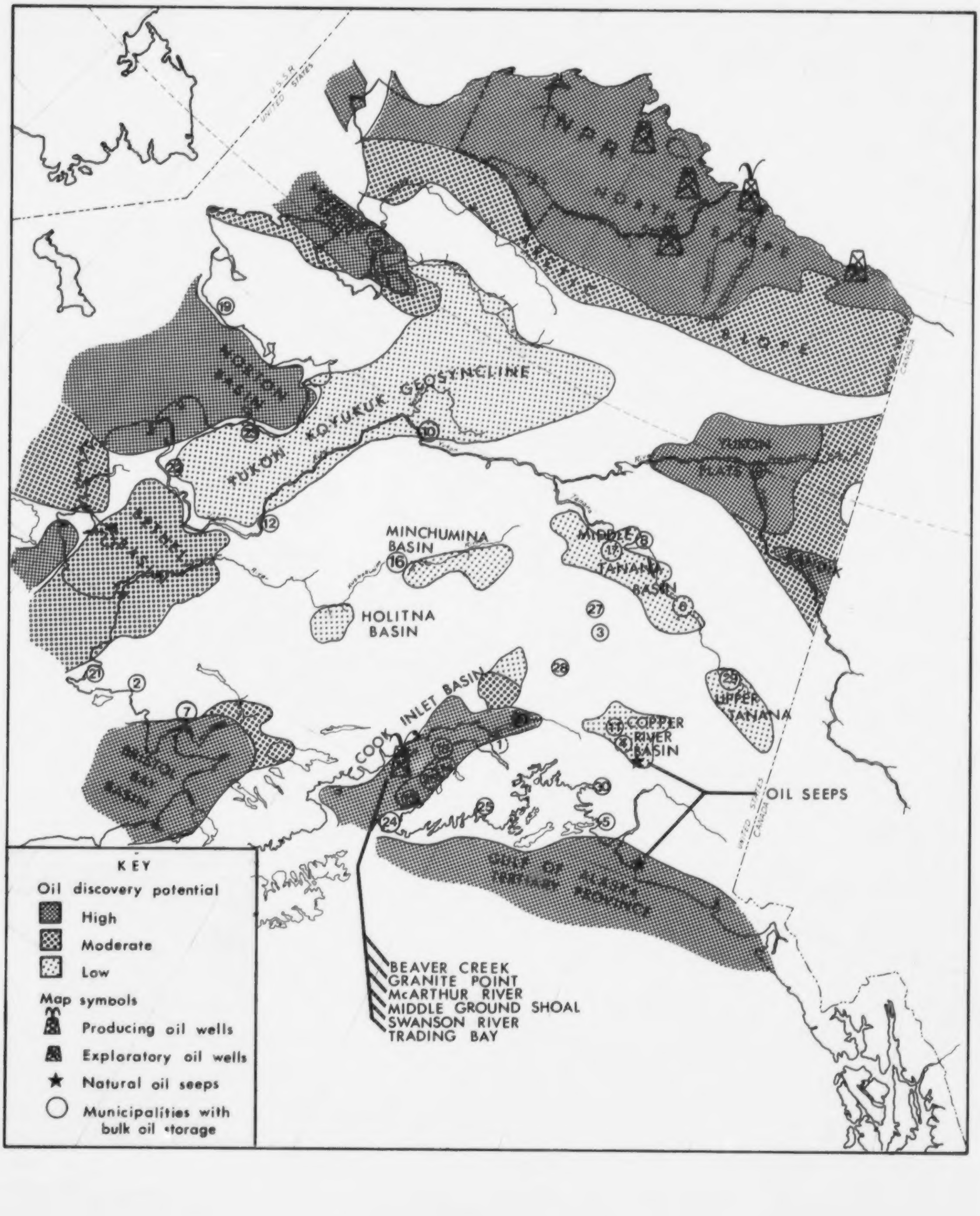

U.S.S.R.
UNITED STATES
N P R
NORTH SLOPE
ARCTIC SLOPE
NORTON BASIN
YUKON KOYUKUK GEOSYNCLINE
BETHEL BASIN
YUKON FLATS
MINCHUMINA BASIN
HOLITNA BASIN
MIDDLE TANANA BASIN
UPPER TANANA
COOK INLET BASIN
BRISTOL BAY BASIN
COPPER RIVER BASIN
OIL SEEPS
GULF OF ALASKA TERTIARY PROVINCE
UNITED STATES
CANADA
BEAVER CREEK
GRANITE POINT
McARTHUR RIVER
MIDDLE GROUND SHOAL
SWANSON RIVER
TRADING BAY
KEY
Oil discovery potential
▩ High
▩ Moderate
▨ Low
Map symbols
Producing oil wells
Exploratory oil wells
★ Natural oil seeps
○ Municipalities with bulk oil storage
1
2
3
5
6
7
10
12
16
17
19
21
24
25
26
27
29
30

Figure 15. Regions with potential oil reserves and municipal oil storage.

TABLE 8. STATE OF ALASKA FIVE YEAR OIL & GAS LEASING SCHEDULE

1979	July	Copper River Basin (Exempt Acreage Sale)
	December	Beaufort Sea (State/Federal Sale)
1980	Early	Relinquished tracts on Arctic Slope (Exempt Acreage Sale)
	Mid	Cook Inlet South of Kenai River (Exempt Acreage Sale)
	Late	Upper Cook Inlet onshore and offshore including the Susitna Valley
1981*	Early	Lower Cook Inlet offshore and onshore (Coordinated with planned Federal Sale)
	Mid	Prudhoe Bay uplands
	Late	Norton Basin offshore and onshore (Coordinated with planned Federal Sale)
1982*	Early	Second Beaufort Sea Sale (submerged lands)
1982*	Mid	Middle Tanana Basin and Copper River Basin
	Late	Southwest Bristol Bay Uplands
1983*	Early	Upper Cook Inlet onshore and offshore including Susitna Valley (possible drainage sales)
	Mid	Chukchi Sea onshore and offshore (Coordinated with planned Federal Sale)
	Mid	Norton Basin
	Late	Minchumina Basin

* Additional exempt acreage sales are also planned for 1981, 1982, and 1983 as acreage in these categories is identified for lease.

regarded as the minimum necessary for full exploration and identification of areas with high potential for return.

Several tracts on the Arctic Slope are nearing expiration on their lease terms and must be relinquished. These tracts will be reoffered if they are not held by production or drilling. Petroleum potential for the general area is considered high, but individual tracts would have to be considered moderate to low as some of these tracts have been drilled without a significant discovery while others remain to be explored. The environmental sensitivity of the area varies according to location. The risk of environmental damage is generally quite low.

The Upper Cook Inlet sale will tentatively include both onshore and offshore tracts. Petroleum potential is judged moderate for the Upper Cook Inlet and low for the Susitna Valley. Potential risks and environmental sensitivity are generally low.

The Lower Cook Inlet will also include both onshore and offshore tracts. Some exploratory drilling is currently taking place. Past exploration in the area has resulted in a few uneconomic discoveries. Potential is considered moderate to high for petroleum discovery. For specific environmental reasons, certain areas will be deleted from the sale. Overall, potential risk and environmental sensitivity in the area are low.

The potential for oil production in the Prudhoe Bay Uplands is considered moderate. Past drilling in the area has not resulted in any significant finds even though the Prudhoe Bay field is directly north of this area. While the environmental risk is considered low, the preservation of the tundra and local plant and animal life are primary concerns.

The petroleum potential of the Norton Sound Basin is largely unassessed although natural hydrocarbon seeps do occur in this area. Environmental sensitivity in Norton Sound is considered moderate and risks appear low.

Petroleum potential for the Middle Tanana Basin is currently judged low. Very limited exploration has taken place. The environmental risks are considered low in this area.

Success in the development of the Bristol Bay Uplands is assessed as low to moderate since little exploration activity has occurred. Drilling in the past has not resulted in any significant finds. The environmental sensitivity and potential risk in the upland area is considered low to moderate.

The Chukchi Sea petroleum potential is considered moderate to high. Exploratory drilling is currently being conducted on NPRA lands. The environmental sensitivity is low during most of the year. Potential risks will be minimized by excluding high risk ice zones.

Little subsurface geological or geophysical data is available for the Minchumina Basin. Presently petroleum potential is judged low. Impacts and environmental risks in this interior basin are expected to be low.

Native corporations are also promoting petroleum development. Doyon Limited, whose acreage covers most of the Yukon region, has contracted for four exploratory wells in the Kandik Basin about 240 km northeast of Fairbanks. The Gulf of Alaska Tertiary Province is controlled by the Chugach Natives Inc. This area has naturally occurring oil seeps and includes early-day oil fields along the coast. More recently deep wells have been drilled along the coast but no commercially exploitable discoveries have been found. The Kotzebue Basin, controlled by the Nana Regional Corporation, has so far proved disappointing with the drilling of two dry holes.

Refineries and Storage

Currently, petroleum refineries are located at Kenai, Fairbanks, and Prudhoe Bay. These refineries handle the majority of the fuel needs for the state. Oil to be used by other cities and villages is transported by barge and stored in large tanks located in the individual communities. The tank sizes vary according to the population in each area, the type of vehicle and home heating requirements in the area, and the remoteness of the village which determines the frequency of oil deliveries. Because of extreme environmental conditions in winter, tanks in remote villages are normally refilled only during the summer season. Table 9 identifies communities in Alaska which require petroleum and indicates the municipal storage capacities. In addition, 3.5 million barrels of fuel is stored at various military facilities. Corporate storage of fuel amounts to another 7 million barrels, and there is an additional storage capacity of 7 million barrels of crude oil in the Alyeska storage tanks in Valdez (26).

IMPACT OF PETROLEUM DEVELOPMENT ON OIL SPILL CONDITIONS

Impact of Petroleum Development on Oil Spill Potential

Petroleum development results in a high potential for oil spills. In the area of development there could be many different types of spills that are likely to occur. These spills include those resulting from servicing construction vehicles and equipment, fuel storage and transfer, plus spills from the exploratory development up to and including a blowout.

Impact of Petroleum Development on Oil Spill Behavior

Petroleum development will not affect oil spill behavior except for the way in which the alteration in land use will affect the movement of the oil after the spill.

Impact of Petroleum Development on Oil Spill Response

Although petroleum development creates the potential for an oil spill, the developing firm can generally be expected to have a high level of capability to respond to spill situations. This capability is likely to be marked by the ability to respond promptly and effectively. Since petroleum development sites are also monitored by regulatory agencies, spills are not likely to go unreported.

TABLE 9. FUEL STORAGE CAPACITIES OF ALASKAN TOWNS IN BARRELS (26)

1.	Anchorage	2,500,000
2.	Bethel	133,880
3.	Cantwell	774
4.	Copper Center	4,113
5.	Cordova	55,917
6.	Delta Junction	2,332
7.	Dillingham	40,746
8.	Fairbanks	144,368
9.	Fort Yukon	17,566
10.	Galena	12,366
11.	Glennallen	3,444
12.	Holy Cross	2,319
13.	Homer	30,558
14.	Kenai	1,559,300
15.	Kotzebue	97,400
16.	McGrath	11,550
17.	Nenana	19,292
18.	Nikiski	20,000
19.	Nome	129,010
20.	Palmer	4,283
21.	Platinum	8,582
22.	St. Marys	3,032
23.	St. Michael	35,903
24.	Seldovia	13,240
25.	Seward	49,128
26.	Soldotna	1,119
27.	Suntrana	1,452
28.	Talkeetna	3,223
29.	Tok	4,745
30.	Valdez	209,301

Impact of Petroleum Development on Site Restoration

Petroleum development firms can be expected to take adequate measures for site restoration. In many cases the site restoration will occur under the direction and surveillance of a regulatory agency.

SECTION 5

ALASKAN INLAND OIL SPILL BEHAVIOR

INTRODUCTION

Because of the many different kinds of petroleum related activities that occur in Alaska, there are also a broad range of different types of spills that may occur. Further, because of the wide variation in types of climate and terrain, an assessment of spill behavior must include the behavior of oil spilled on land and water in both frozen and unfrozen conditions. The following subsections present a general description of the spreading process together with some predictive relationships for the motion of the oil. These subsections describe the following types of spill behavior:

- Oil spilled on open water
- Oil spilled on frozen ground and ice
- Oil spilled on snow
- Oil spilled on water during freezeup
- Oil spilled on water under ice
- Oil spilled on water at breakup
- Oil spilled on gravel
- Oil spilled on soil
- Oil advected by ground water.

The actual behavior of spilled oil may at some stage be described by several, if not all, of the phenomena presented. For example, oil may first be spilled on a soil surface, then spread on and in the soil until it reaches ground water or permafrost. The oil may then spread underground until encountering a body of water where it becomes liberated from other restraints and free to spread on the water. Spill behavior will also be dependent on the time of year, the extent of weathering of the oil, and how the climate changes after the spill.

Evaporation plays a major role in determining the behavior of spilled oil. Spills of some refined products, such as arctic diesel, may be reduced by 50% or more a day because of evaporation. This section therefore concludes with a method of computing evaporation rates for various types of crudes and refined products.

OIL SPILLED ON OPEN WATER

Oil spilled on still water can spread radially from a point source or linearly from a line source. The moving front of the slick is driven first by a hydrostatic (gravity) force and later by surface tension. The horizontal gravity force is the result of vertically integrating the hydrostatic pressure through the slick. Surface tension controls the resulting oil-water interface as the slick assumes the shape having the lowest potential energy. These driving forces are restrained by inertia and viscous forces in the water which act to retard the spread of the slick. As the slick spreads, it undergoes an energy changing process associated with each force acting on the slick (27). Because of this, the oil progresses through three distinct stages during spreading. In the early stage, referred to as inertial spreading, the hydrostatic driving force within the slick is balanced by the inertia of displacing surface water. As the areal dimension of the slick increases, a viscous shear retarding force begins to dominate. This is called the viscous regime. As the slick expands, it also decreases in thickness until the hydrostatic force ceases to drive the spreading. The slick will then be controlled by surface tension balancing the viscous retarding force. This is referred to as surface tension spreading.

Fay (27) determined an order of magnitude estimate of the extent of oil spreading in each regime as:

Regime	One-Dimensional Slick	Axisymmetric
Inertial	$\ell = 1.5(\Delta g A t^2)^{1/3}$	$= 1.14(\Delta g V t^2)^{1/4}$
Viscous	$= 1.5(\Delta g A^2 t^{3/2}/\nu_0{}^{1/2})^{1/4}$	$= 1.45(\Delta g V^2\ t^{3/2}/\nu_0{}^{1/2})^{1/6}$
Surface Tension	$= 1.33(\sigma^2 t^{3/2}/\rho_0{}^2 \nu_0)^{1/4}$	$= 2.30(\sigma^2 t^3/\rho_0{}^2 \nu_0)^{1/4}$

where

A - is the plan area of the oil slick,
V - is the volume of oil spilled,
ℓ - represents one-dimensional spread extent,
R - is the radial spread extent,
Δ - is the relative density difference = $\frac{\rho_w - \rho_o}{\rho_w}$
σ - is the net surface tension,
ν_0- is the oil kinematic viscosity,
t - is the time of spreading,
ρ_0- is the density of the oil,
g - is the gravitational acceleration,
ρ_w- is the density of the water,

and the constant coefficients are determined by experimental observations.

The final extent of spreading is reached well into the surface tension regime, and the cause of spread termination, or slick equilibrium, is suggested by both Fay (27, 28) and Hoult (29). In Fay's earlier work (28) he theorized that cessation of spreading is caused by the evaporation of some oil fractions which reduces the spreading coefficient to zero. Estimates resulting from this theory were an order of magnitude smaller than observed values. Later modifications to this theory suggests the spreading coefficient is reduced by an increase in water-oil surface tension brought about by the dissolving of oil fractions in the water layer beneath the oil film. Hoult mentions Blokker's theory that oil spread ceases after a certain minimum thickness is reached, this thickness being 0.025 mm. Another physical mechanism for reducing spreading may be the biological degradation of the oil due to bacterial action which will change the properties of the oil (29).

The movement of an oil slick is not only a function of spreading, but also of environmental factors such as waves, winds, and currents. Wave effects are not particularly important on oil spills in inland water bodies, except on very large lakes where the fetch and wind conditions allow adequate wave generation. Hoult (29) states that wave effects can generally be ignored due to the oscillatory water particle motion which has a zero average displacement. However, in reality, there is net water particle movement caused by waves, called Stokes transport. This transport, in combination with induced streaming, are the mechanisms for the direct movement of surface oil due to waves. Induced streaming is the result of momentum transferred to the oil from short period waves that are damped out by the presence of the oil. Wave shadowing is an indirect effect of waves on slick transport that essentially decreases slick velocity. This shadowing is a reduction in wind contact with the oil because of the presence of wave forms at the water surface.

Slick velocity is also affected by winds. Isakson, et al. (30) use a vector addition method, superimposing wind velocity directly onto spreading and current effects to determine the slick propagation speed. The surface wind drift vector is generally determined to be 1 to 5% of the wind speed at 10 m above the water surface, and directed 20° to the right of the 10 m wind speed (Eckman drift). O'Brien (31) and Keulegan (32) find that the surface fluid velocity, U_s, is 3.3% of the wind velocity, U_{10}, measured at 10 m above the water surface:

$$U_s = 0.033\, U_{10},$$

for high Reynolds Number which will occur at sea or in harsh environments. Wind driven transport is more significant as compared to wave effects by as much as a factor of five (33), and the two effects are found to work together in driving a slick only at low wind speeds (34) up to about 1.5 knots.

Currents work with wind, waves, and spreading in moving an oil slick. The current velocity vector parallel to the wind, however, has been found not to simply add with the other vectors due to coupling with the wind vector (33, 35). Laboratory experiments have shown the coupling factor to be 56%.

The resultant oil slick drift velocity vector, $\vec{D}$, is then computed by combining the effects of environmental factors and spreading as:

$$\vec{D} = \vec{U} + 0.033\,\vec{U}_{10} + 0.56\,\vec{C}_p + \vec{C}_c,$$

where

$\vec{U}$ = spreading velocity vector due to gravity, surface tension, and viscous forces,

$\vec{U}_{10}$ = wind velocity vector 10 m above the water surface,

$\vec{C}_p$ = current velocity vector parallel to the wind,
$\vec{C}_c$ = current velocity vector perpendicular to the wind (cross-wind)

Many other phenomena exist which affect slick movement on open water. Weathering, the loss and breakdown of componets of the oil due to turbulence and evaporation, occurs very quickly on open water. Oil properties change and therefore oil behavior changes as weathering progresses. Unexpected behavior is sometimes observed, such as oil becoming neutrally buoyant or sinking to the bottom as a result of an increase in the specific gravity of the oil as lighter volatiles evaporate. The sinking rate will accelerate with depth because oil is more compressible than water causing its density to further increase. Oil then can drift deep in the water column, or along the bottom, virtually undetectable until it comes ashore as happened in the recent Ixtoc I oil spill in the Gulf of Mexico.

Mousse, a water/oil emulsion, has been observed to form in open ocean oil spills where ocean turbulence mixes the oil and water into a thick, high viscosity fluid. This mix is difficult to recover and difficult to separate after recovery.

OIL SPILLED ON FROZEN GROUND AND ICE

The spread of oil spilled on frozen ground or ice is driven by the hydrostatic force within the oil slick. Several investigators have attempted analytical predictions of the spread of oil over a horizontal surface by balancing the hydrostatic force with an inertia force, a viscous force, or surface tension forces (36-39). The balance of inertia and gravity occurs during the initial stages of a spill. As the slick grows thinner with increased girth, a viscous retarding force dominates. As the slick further expands and thins, it approaches a steady state balance between the force of gravity and surface tension.

In the inertial range, Hoult (37) found that oil would spread according to the relation:

$$R = 0.55 \left(\frac{\rho_w g Q^2}{\rho_0 \eta} \right)^{1/6} t^{2/3}$$

where

R - is the radial spread extent,
Q - is the volumetric oil discharge rate,
η - represents ice roughness height,
t - is the time of spreading,
ρ_w - is the density of water,
ρ_0 - is the density of oil,
g - is the gravitational acceleration.

In the viscous range, Chen et al. (38) suggested that the spread of oil should be described as:

$$R = 0.24(tgV^2/\nu_0)^{1/5} + 0.35V^{1/3}$$

where V - is the volume of oil and
ν_0 - is oil viscosity.

McMinn (39) balanced gravity and surface tension to determine the final thickness of a slick, δ, given as:

$$\delta = \left(2 \frac{\sigma}{\rho_0 g}\right)^{1/2},$$

with the surface tension, σ, related to its contact angle, α, according to the relation

$$\sigma = \sigma_0 (1 - \cos\alpha)$$

where σ_0 is the interfacial energy between oil and air. He also observed in field measurements that the thickness of a slick never decreases to this value, and hence the surface tension regime does not exist for the spreading of oil on ice or frozen ground.

OIL SPILLED ON SNOW

Oil that is in thermal equilibrium with its frozen surroundings generally results in only limited horizontal spreading (40). Depending on the porosity and permeability of the snow, the oil does soak in fairly rapidly with little compaction of the snow cover. The oil generally does not penetrate into the frozen soil. Some limited penetration of the oil into the ground surface can occur through small, randomly distributed, vertical rivulets to a depth less than 20 cm. New snow covering the spilled oil apparently does not suppress short wave solar radiation. Local heating results, causing melting and sublimation which proceeds upwards. Down-slope migration of the oil begins with the spring melt water runoff.

Hot oil spills penetrate snow very rapidly. The vertical flow is controlled by the snow melting. Approximately two volumes of oil are required to melt one volume of snow. The volume of snow melted will thus tend to be less than the volume of oil discharged and oil will back up in the hole. As the hot oil melts the snow, the oil-water mixture rapidly penetrates into fresh snow due to both gravity and the impact pressure of the oil being discharged.

The melt hole deepens and simultaneously the oil-water mixture permeates the snow horizontally. Once the melt hole reaches ground level, there is rapid spread of the oil under the snow along the ground with no accumulation of oil. The oil then quickly cools and does not penetrate into the underlying frozen soil.

When oil begins to flow down an inclined surface, the gravity driving force is increased because of the added influence of the slope. The retarding force is the shear between the oil and the surface. Provided the flow remains laminar, i.e., the slick Reynolds number $R_e = 4\delta\bar{u}/\nu_0$ is less than 25, (41) the mean velocity of the slick $\bar{u}$ can be given as:

$$\bar{u} = \frac{g\ \delta^2 \cos\beta}{3\nu_0}$$

where β is the angle of the slope. The thickness is thus given as:

$$\delta = \sqrt[3]{\frac{3\ \nu_0\ Q}{g\ w\ \cos\beta}}\ .$$

where w is the slick width. If the speed of advance increases into the turbulent range, the thickness and the speed can be calculated from the Manning equation applied to very wide, open channel flow:

$$\bar{u} = \frac{\delta^{2/3} \cos^{1/2}\beta}{n} \text{ in meters/sec.}$$

where δ has dimensions of meters and n has dimensions of sec/m $^{1/3}$. Solution is possible by assuming a thickness and calculating a mean velocity. The product of the thickness, width, and velocity is then compared against a known flowrate and the thickness is adjusted in the above expression until the derived and known flowrates match (42). The roughness of the surface or the presence of vegetation is compensated for in the value of n.

While it is easy to picture oil moving as an expanding slick, the actual spread tends not to be steady. Oil will find gullies to flow along, moving in rivulets rather than in a continuous front. Often the slick encounters depressions in the surface which fill before spreading farther (43).

OIL SPILLED ON WATER DURING FREEZEUP

The formation of ice in rivers first occurs in quiet backwater areas, while the main current keeps the channel clear of ice. Eventually frazil ice nucleating in the main stream begins to clump forming small pancakes and floes. These begin to freeze together as they are carried downstream until a solid cover is developed (44). If a spill occurs during this formation period, the oil will tend to be captured between the floes. Oscillatory motion of the floes will pump the oil through the pancake field and up onto the floes. As the contaminated slush ice caught between the floes begins to freeze the oil will become frozen in place. Oil pumped up onto the ice will remain there, corraled by the raised rims of the pancake ice which are the result of colliding floes. In one test, 58% of the oil spilled in a forming ice field was pumped up onto the ice (45).

The freezing of oil into the ice is not strictly limited to the ice formation stage. Aufeis or overflow ice can grow over the formed ice once the cover is established. Aufeis is the result of the water under the ice becoming pressured due to the downward growth of ice. This forces water back up through fissures in the ice or from infrozen portions of river banks. Ground water passing through a porous bed is similarly affected. Commonly the flow path is squeezed between the down growing freeze front and the permafrost. This forces unfrozen water back up onto the surface to freeze on the surface. The pressurizing of underlying water continues for the entire freezing season or until the river is frozen solid (46). Therefore oil spilled onto an ice covered river will become trapped in the continually forming aufeis and remain in place until the spring thaw.

OIL SPILLED IN WATER UNDER ICE

Since the density of oil is less than the density of water, oil which has spilled beneath an ice cover will begin to pool on the underside of the ice. The growth of the slick under quiescent conditions has been predicted by Hoult (37) to follow the relation:

$$R = 0.55 \left[\frac{(\rho_w - \rho_0) g Q^2}{\rho_0 \eta} \right]^{1/6} t^{2/3},$$

where

Q - is the flow rate
η - is the under-ice roughness
ρ_w - is the density of water
ρ_0 - is the density of oil
t - is the time of spreading.

Once the spreading has stopped, the thickness under a smooth ice cover can be predicted to be:

$$\delta = \left[\frac{2\sigma}{(\rho_w - \rho_0) g} \right]^{1/2},$$

where σ is the net surface tension accounting for the contact angle between the oil, water, and ice (42). Generally, even "smooth" ice sheets will be characterized by depressions and undulations. Oil will spread under the ice following these channels. The oil may therefore not form a simple uniform pool. Its size and thickness will reflect the actual geometry of the under-ice roughness (47).

Uzuner, et al. (48) carried out some experimental studies on the transport of oil under smooth ice by a current. They observed that the slick behavior varied for different types of oil. Crude oil typically spreads laterally while moving in the direction of the current. No. 2 fuel oil slicks behaved in the opposite fashion, becoming longer and narrower. High currents were not observed to cause the formation of mousse. In general, the slick speed, U_s, for crude is given as:

$$U_s = 8.6 \times 10^{-6}\ U_w^{4.29},$$

for ranges of current speed, U_w, between 8 and 28 cm/sec. From 28 to 36 cm/sec the crude slick varied linearly according to:

$$U_s = 1.10\ U_w - 16.60.$$

No. 2 fuel oil appeared to follow a linear relation throughout the current range:

$$U_s = 0.38\ U_w - 1.36.$$

Discontinuities in the under-ice surface limit the spreading of an oil slick. Moir and Lau (49) simulated ice ridges and observed that oil could pool in front, between, or behind obstacles to flow whenever the free stream densimetric Froude number did not exceed approximately 0.5. Lewis (50) observed, based on the findings of others, that oil will remain trapped in rough ice of 20 cm amplitude provided the current is less than 30 cm/sec. In some current research by Schultz and Cox (51), the conclusions of Moir and Lau and the observations of Lewis are being verified. They found that when the ice roughness exceeded the static thickness of the oil slick, the oil remained trapped, provided the free stream densimetric Froude number does not exceed 0.5. Flow conditions having a Froude number exceeding 0.5 caused the trapped oil to wash out and be transported downstream.

When the roughness is less than the equilibrium thickness, the slick can advance, but at a much retarded rate as compared to spreading under smooth ice. The threshold current velocity causing the slick to move is increased from approximately 7 cm/sec for smooth ice to 26 cm/sec when the roughness approaches 1 cm in amplitude (51).

In general oil under a natural ice cover will be expected to remain trapped within the bounds of a rough ice field regardless of the current speed. The oil may meander through natural channels formed under the ice. It will spread relatively easily in smooth ice if the current exceeds 7 cm/sec. The formation of mousse beneath an ice cover should be minimal.

OIL SPILLED ON WATER AT BREAKUP

Since the majority of rivers north of the Yukon freeze solid during winter, initial melting of the ice takes place at the ice surface. The melting would be accelerated by the black body effect of oil in ice. Any oil trapped near the surface would be carried off with this surface runoff. Since there is no well defined channel for the surface runoff, the oil and runoff may spread in a more undefined manner across the floodplain (52).

Gradually some discharge beneath the ice develops, lifting and fracturing the ice. Water then rises through the fractures further flooding the ice sheet and accelerating the melt. The sheet gradually weakens and breaks into large floes. As they move downstream the floes are continually rotated, overridden, underridden, turned over, and broken up by impact with adjacent ones. Ice with smooth, vertical walls is left along the shore. Oil spilled during this period will be herded between the parallel shorefast ice walls and will gather between the floes.

Tests of Prudhoe Bay crude and No. 2 diesel fuel were conducted by Schultz (53) in a broken ice field at 95% concentration. Ice pieces ranged from 30 x 30 x 25 cm to brash ice. When the crude oil was poured in the broken ice field, it built up in thickness between the ice pieces rather than spreading. After 90 liters of crude were deposited, the slick covered an area of only 2.8 m^2. On temperate waters, the same volume would cover approximately 28 m^2. The oil thickness in the center was 9.4 cm, varying to about 6.4 cm near the boundary. No. 2 oil was spilled under the same conditions and it spread rapidly through the broken ice field. The equilibrium thickness of oil spilled in a static broken ice field is therefore highly variable, likely being a function of the properties of the oil, the concentration of the broken ice field, and the size distribution of the ice pieces.

During the 1977 Buzzards Bay spill (54), diesel oil that was incorporated in the relatively stable ice began to be released upon breakup. The ice floes that resulted contained various amounts of oil. As the ice floes further deteriorated, oil that had penetrated into the ice streamed from the floes in the form of sheen. This allowed the oil to travel a considerable distance with the ice in some instances before being released into the open water. Contaminated ice floes that drifted into coves settled on the beaches and leached the oil into the sediments and beach grasses.

In the 1977 ETHEL H spill on the Hudson River (55), No. 6 oil spilled in a broken ice field behaved differently. Prior to the spill, ice floes created from the breakup of the shorefast ice covered 80% of the river at some locations. As these ice floes traveled down the river, it was observed that heavy tarry oil adhered to many of the ice floes. In some instances, the ice floe surface was 50% covered with oil. A thin sheen of oil was observed streaming from some of the more heavily oiled ice pieces. When the ice floes became packed together, the oil between the floes was contained to a greater thickness. As the contaminated ice left the mouth of the Hudson to enter the Atlantic, the heavy oil would move along with the broken ice and slowly bleed off in the form of a sheen.

From these observations, it can be concluded that diesel oil spilled in a broken ice field will penetrate into the ice and flow between the ice pieces depending upon the concentration of the ice field. Crude oil spilled in broken ice conditions would typically adhere to the ice surfaces and bleed oil sheen, or the lighter ends, into the surrounding waters. The heavier crude would have a far greater tendency to be contained by the broken ice pieces with a resulting greater oil thickness. If there is enough interaction between the oil and ice, all of the heavy ends of the spill could possibly adhere to the ice surfaces. The oil which adheres to the ice would cause melt pockets or holes to form in the ice surface during warming periods due to the albedo differences.

OIL SPILLED ON GRAVEL

Rivers north of the Yukon freeze solid during the winter season. Occasional pockets of unfrozen water can exist in deep holes in the river bottom but there is no net river flow over the surface of the stream bed, although some flow may occur through the bottom sediments. Spilled oil may seep down through fractures in the ice or leak into the stream bed from a subterranean leak. Once within the stream bed the oil may migrate through the gravel bottom beneath the frozen river. If the source of the spill is a buried pipeline rupture, the heated oil can move through the gravel with relative ease. The average migration rate can be expected to be less than 15 cm/sec (12).

OIL SPILLED ON SOIL

When oil is spilled on unfrozen soil it can spread both laterally and vertically. Experiments of oil spilling on thawed tundra demonstrated that the oil spreads initially on the surface but only until it can soak into the soil. This lateral spread is only of the order of a few meters in the case of a small spill.

Little horizontal spreading occurs once the oil permeates into the detritus layer. The depth of penetration is a function of the retention capacity of the soil and the viscosity of the oil. Generally the sorbent capacity of the soil decreases with decreasing organic content. The higher molecular weight components of the hydrocarbons are most easily absorbed by the soil (43). The maximum depth of penetration (in meters) is given by:

$$D = \frac{KV}{A}$$

where

V - is volume spilled,
A - is area of infiltration,
K - is a constant for different soils and oils.

Permafrost of the ground water table will serve as a barrier to further descent of the oil. If little ground water movement occurs, the maximum spreading of the oil lens on the water table is given by:

$$S \quad \frac{1000}{H} \left(V - \frac{A \cdot d}{K} \right)$$

where

S - is maximum spread area
A - is area of infiltration
H - is the thickness of the oil layer in the capillary zone
d - is the depth to groundwater.

Values for K and H should be experimentally determined for each field site. Some typical values are given in Table 10 (56).

The presence of spilled oil in the soil will affect its heat capacity and albedo. The thickness of the active layer will increase 22 to 44% because of the hydrocarbon contamination. In comparison, complete removal of the moss-detritus layer would result in a 100% increase in active layer thickness. The effect of oil on the permafrost layer appears to be less than the effect of a wildfire.

TABLE 10 TYPICAL VALUES FOR K AND H (56)

SOIL	K			H (mm)
	Gasoline	Kerosine	Light Fuel Oil	
Course gravel	400	200	100	5
Gravel to course sand	250	125	62	8
Course to medium sand	130	66	33	12
Medium to fine sand	80	40	20	20
Fine sand to silt	50	25	12	40

Oil permeating into soil weathers much more slowly than exposed oil. Probably most of the benzene and toulene is lost in the first year. The toxic polynuclear aromatics will not be lost by weathering. This suggests that the oil can maintain a lower viscosity for an extended period of time, and may be free to migrate early with a rising water table, causing extended ecological damage.

The oil seems to remain mobile for about a year and, depending on the slope and ground water conditions, could probably move through the detritus layer a distance of 10 to 100 m.

A spill in the spring with high runoff may be expected to behave in a substantially different manner even though the ground is unfrozen. It is likely that the oil will spread relatively rapidly assisted by the moving water, and will thin out to a depth of about 1 cm. It is possible that much of the vegetation will be protected from the oil by the water, especially where the ground water level is at or above the surface, preventing the oil from coating the vegetation or soaking into the soil.

MacKay (43) has examined the results of several experimental spills and developed an argument for scaling up the results to a larger scale.

> "A cold oil winter spill will have the lowest area of about 5.5 $V^{0.89}$ m^2 where V is the spill volume (m^3). This will increase on thawing by a factor of about 5.5 to 30.$V^{0.89}$ m^2. A 50,000 bbl spill will thus cover an area of about 16000 m^2 (3.9 acres) spreading to 89000 m^2 (22 acres) after the thaw.
>
> A hot oil winter spill will spread immediately to an area of about 30$V^{0.89}$ m^2, the same area as a cold oil spill after thaw. Again, a 50,000 bbl spill will cover 89000 m^2 (or 22 acres).

A spring spill will cover the largest area of about 100 $V^{0.89}$ m^2. Thus a 50,000 bbl spill will spread over about 300,000 m^2 (or 74 acres).

A summer spill will cover a surface-contaminated area of about 9.5 $V^{0.89}$ m^2 although this may vary considerably according to the depth of the moss/detritus layer. In the early summer where the active layer depth is shallow the area could be almost doubled to 20 $V^{0.89}$ m^2 or in the late summer halved to about 5 $V^{0.89}$ m^2. A 50,000 bbl spill will thus cover about 28000 m^2 (6.9 acres) but this could range from 12000 to 50000 m^2 (3 to 12 acres).

Surrounding and especially downhill of the surface-contaminated area will be a subsurface-contaminated area corresponding to a perimeter of 10 to 20 m. Analyzing the experimental spill data suggests that if the surface-contaminated area is A m^2 then the subsurface area will be an additional 48$\sqrt{A}$ m^2. A spill area of 10,000 m^2 thus corresponds to 4800 m^2 or an additional area of 48%, whereas at a spill area of 100 m^2 it corresponds to 480 m^2 or an additional 480%. It is probable that this subsurface area will be very sensitive to the topography and to the promptness in instituting containment measures. These estimates are maxima. A 50,000 bbl spill may thus contaminate an additional subsurface area of up to 8000 m^2 (2.0 acres) giving a total spill area of about 36000 m^2 (8.9 acres)."

OIL ADVECTED BY GROUND WATER

Due to the relative insolubility of hydrocarbons in water, the ground water table acts as an impermeable barrier to the downward migration of spilled hydrocarbons (57). As a result, the dispersion of hydrocarbons is basically limited to the curviplanar surface of the water table. Hydrocarbons, being buoyant and insoluble, will be forced to flow in the direction of least resistance on top of the water table. The transport is therefore controlled by the ability of the hydrocarbons to circumvent obstructions within this plane of flow. Thus two major factors act in conjunction to control hydrocarbon dispersion; barriers to planar flow which retard flow under static conditions, and water table fluctuations which permit hydrocarbons to flow under or over these obstacles.

Hydrocarbons spilled into unconsolidated soil begin to saturate the soil as soon as they are released. Relatively large volumes lost over short periods of time will develop mounds. The mounds are supported by the relative porosity, permeability, and adsorption characteristics of the base materials which resist downward flow. Dispersion occurs as the product moves out on the water table from the "leaking" mound. As a result, the major flow direction of the hydrocarbons will coincide with the major flow direction of the shallow ground water system.

Many of these dispersion characteristics change in consolidated materials. In sedimentary rocks, the orientation of the rock and the primary depositional characteristics of the unit are as critical as porosity and permeability. If the dip of the stratified rock is shallow, facies changes and sorting and packing characteristics control dispersion and dispersion rates. Under these circumstances, the water table is essentially within a single geologic unit and lateral changes in texture act to impede flow. The hydrocarbons flow at an angle to the local ground water system as it moves around these obstacles (Figure 16). In more steeply dipping rock units, the dominant flow direction is parallel to the strike, downslope rather than down the dominant local hydraulic gradient (Figure 17).

In carbonate rocks, unit orientation solution openings and fractures control the dispersion. Hydrocarbons can escape through highly soluble underlying limestone layers. Surface outcrops provide direct avenues of escape for spilled oil. Once within the carbonate layers, the hydrocarbon may spread through the complex network of solution openings and fractures. In some cases, these systems can hold the hydrocarbons for long periods of time.

Water table fluctuations permit considerable dispersion in carbonate terrain. Spilled product can migrate through the soil until it enters a solution channel where it is impounded on top of the water table. A rising water table can then lift the hydrocarbons over an obstacle to higher solution channels where dispersion will continue. Some product will be left behind in pockets when the water level drops. As the fluctuations in the water table continue the product can then be pumped upslope.

EVAPORATION

Since some crudes and refined products have high evaporation rates, it is important to be able to compute evaporation rates in order to determine how much oil is available for spreading or recovery. A recent paper by Nadeau and Mackay (58) provides a comprehensive method of determining the evaporation of petroleum products. The method of making these calculations is relatively easy and will be briefly described in this section. Necessary curves for making these calculations are also included. It is expected that this method of calculating evaporation rates will be helpful both in contingency planning and in spill response.

Evaporation rate has been found to be a function of the mass transfer coefficient, the area of the spill, the time available for evaporation, the temperature, and the type of hydrocarbon that has been spilled. The paragraphs that follow briefly describe the Nadeau/Mackay method of computing evaporation rates based on these physical parameters.

Mass Transfer Coefficient

The mass transfer coefficient measures the rate at which hydrocarbon vapor at the spill surface is carried away by wind into the atmosphere. Figure 18 shows the mass transfer coefficient, k, as a function of wind speed.

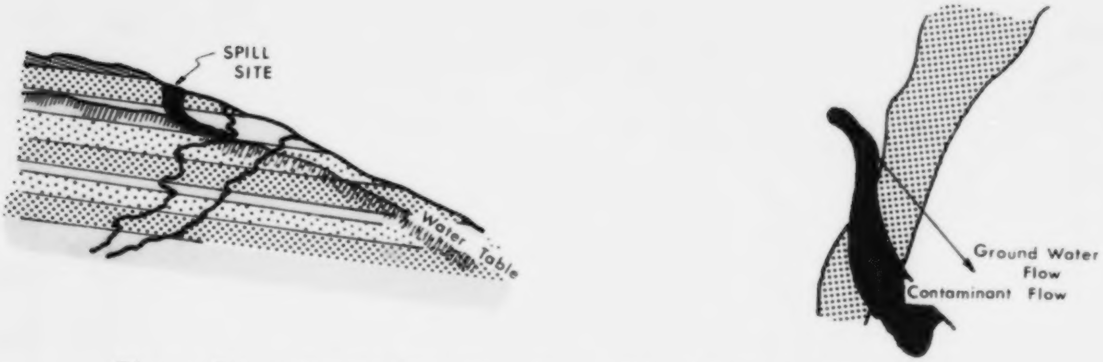

SPILL SITE
Water Table
Ground Water Flow
Contaminant Flow

Figure 16. Hydrocarbon flow diverted by lateral variations in shallow dipping sedimentary rocks.

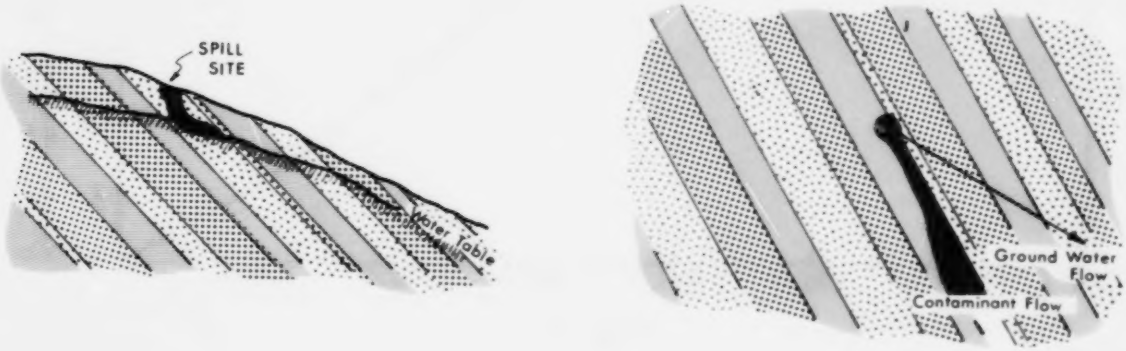

SPILL SITE
Water Table
Ground Water Flow
Contaminant Flow

Figure 17. Hydrocarbon flow paralleling the strike direction in steeply dipping sedimentary rock.

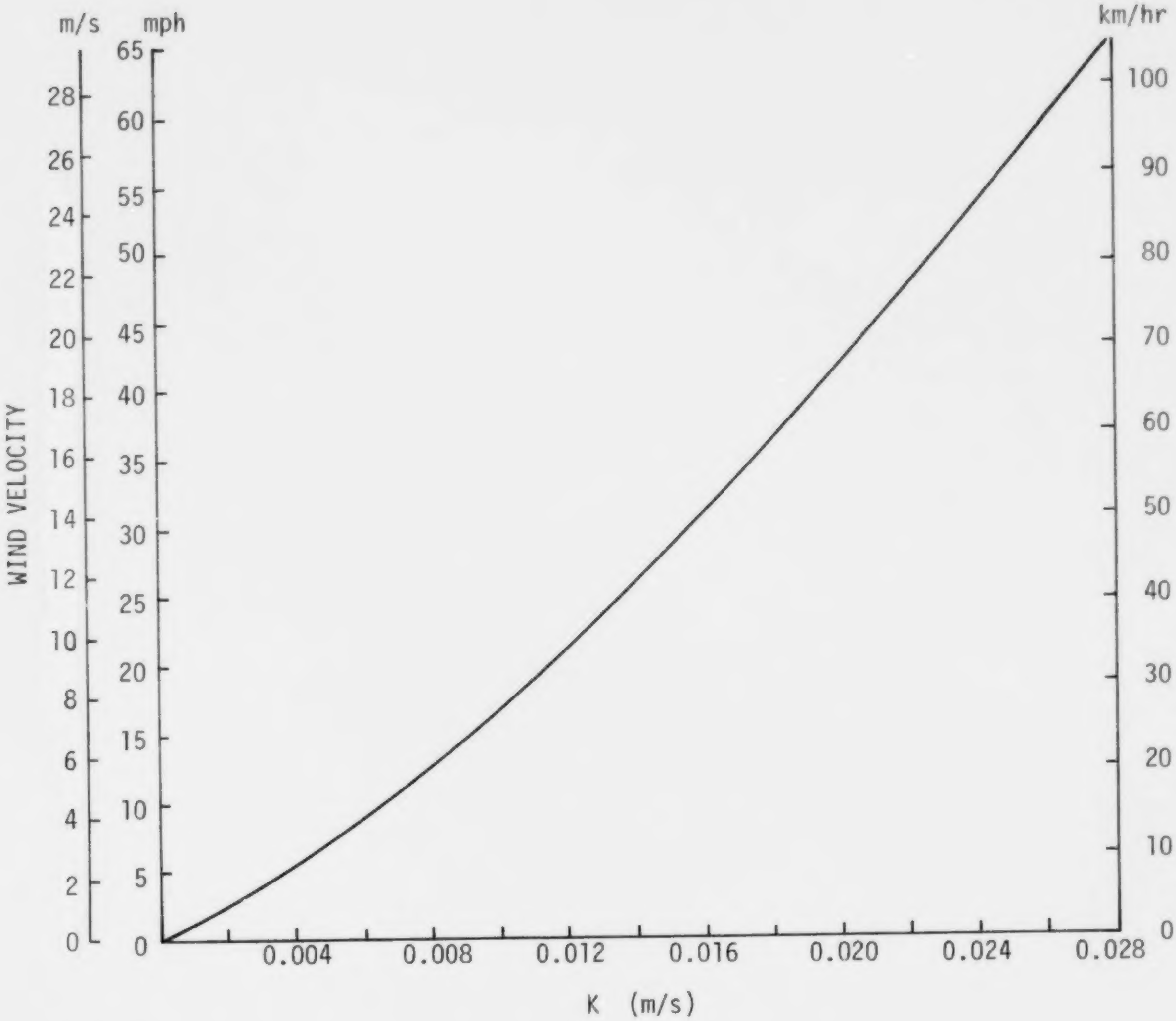


Figure 18. Determination of the mass transfer coefficient K from the wind velocity (58).

Area of Spill

Evaporation is a function of the area of the spill exposed to the atmosphere; the larger the area exposed, the faster the evaporation. For these calculations, area has the dimensions of m^2/kg. Area can be calculated in one of two ways depending on the parameters that are known.

$$A = \frac{1}{(\text{spill thickness})(\text{fuel density})} = \frac{1}{(m)(kg/m^3)} = \frac{m^2}{kg}$$

If the area and volume of the spill are known, these parameters can be entered directly rather than slick thickness.

$$A = \frac{(\text{spill area})}{(\text{spill volume})(\text{fuel density})} = \frac{m^2}{(m^3)(kg/m^3)} = \frac{m^2}{kg}$$

Time Available for Evaporation

The longer the slick is exposed, the more it evaporates. For these calculations time is entered in seconds. When the physical parameters are constant, it may be convenient to perform a series of calculations with time as a variable to determine the amount of oil that has evaporated over a period of hours or days.

Temperature

Evaporation rate increases with temperature. Generally ambient air temperatures are known at the spill site; however, the spilled oil is more likely to have the temperature of the surface below it. For example, oil on water or ice may be assumed to have the temperature of these surfaces. Also, if a highly volatile product is evaporating, it is likely to be chilled by the evaporation. On the other hand, a spill on a dark surface may absorb radiation and be warmer than the surrounding area.

Types of Hydrocarbon

Evaporation rates are dependent on the types of hydrocarbon being considered. The highly volatile gasolines evaporate more quickly than the heavier oils. These differences are taken into account using separate curves for the evaporation of each petroleum product.

Sample Calculation

Assume that a spill of about 6300 bbl of crude (1000 m^3) is moving down a stream. Calculate the evaporation rate.

- Temperature: 5°C
- Dimensions of contaminated area: stream 20 m wide
- Oil has moved 10 km downstream
- Crude API gravity: 30
- Spill volume: 1000 m^3
- Wind velocity: 6 m/sec

- From Figure 18, a wind velocity of 6 m/sec corresponds to a mass transfer coefficient K of 0.008 m/sec.

- Figure 19 shows crude with API gravity of 30 has a density of 875 kg/m

- Calculate the area:

$$A = \frac{\text{(spill area)}}{\text{(spill volume)(fuel density)}} = \frac{20 \text{ m} \times 10 \times 10^3 \text{ m}}{1000 \text{ m}^3 \times 875 \text{ kg/m}^3}$$

$$A = 0.229 \text{ m}^2/\text{kg}.$$

- Figures 20 through 26 show the fraction of fuel remaining for various petroleum products. All of the curves that are available are shown here to provide the field engineer with the information needed to solve a wide variety of practical problems. These curves are plotted in terms of KAt, where t is time in seconds.

  For an example, determine the fraction remaining at the end of one day.

$$KAt = 0.008 \text{ m/sec} \times 0.229 \text{ m}^2/\text{kg} \times 24 \times 60 \times 60 \text{ seconds} = 158.3 \text{ m}^3/\text{kg}$$

- Using the computed value of KAt for a 24 hour period, and a temperature of 5°C, go to Figure 24 showing light and medium crude oils and read a fraction of fuel remaining of 78% after a one day period of evaporation.

- Set-up a schedule of expected evaporation for a period of a week. KAt was computed for a one day period; over a period of a week values of KAt are multiples of the value computed for one day. For each new value of KAt, read a percent oil remaining in Figure 24.

TABLE 11 PERCENT EVAPORATION WITH TIME

DAY	KAt	% REMAINING
1	158	78
2	317	75
3	475	73
4	633	72
5	792	72
6	950	72
7	1108	71

Table 11 shows that 22% of the spill evaporates in the first day, but that after the fourth day very little additional fuel is lost by evaporation. It is also instructive to notice what Figure 24 shows in general terms. At very low temperatures, -30°C and -20°C, only a small fraction of the spill is lost to evaporation. As the temperature increases, much more is lost, but most of the evaporation occurs soon after the spill. For even the highest temperatures, the evaporation rate is low for values of KAt greater than 1000.

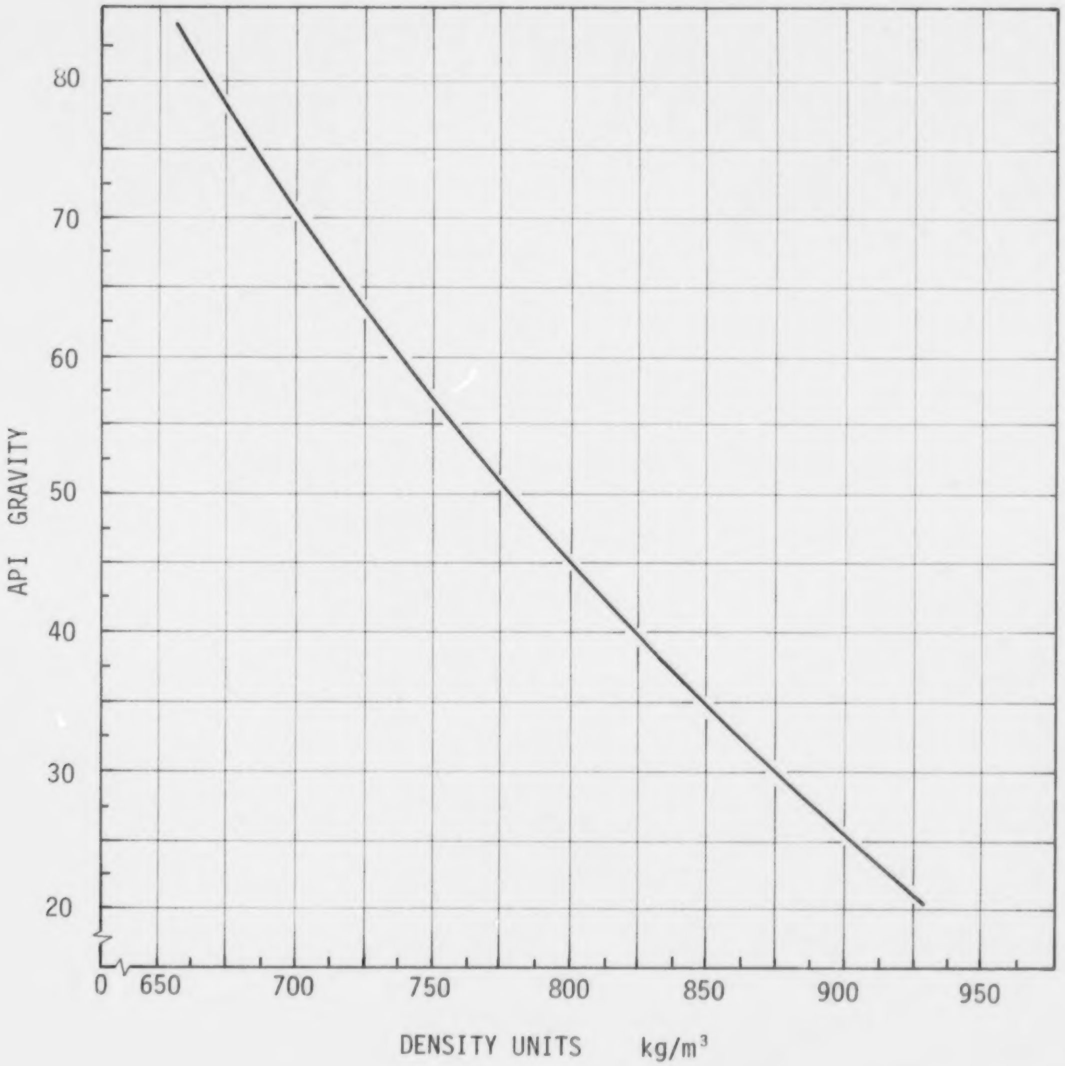


Figure 19. Conversion of API gravities to conventional density units.

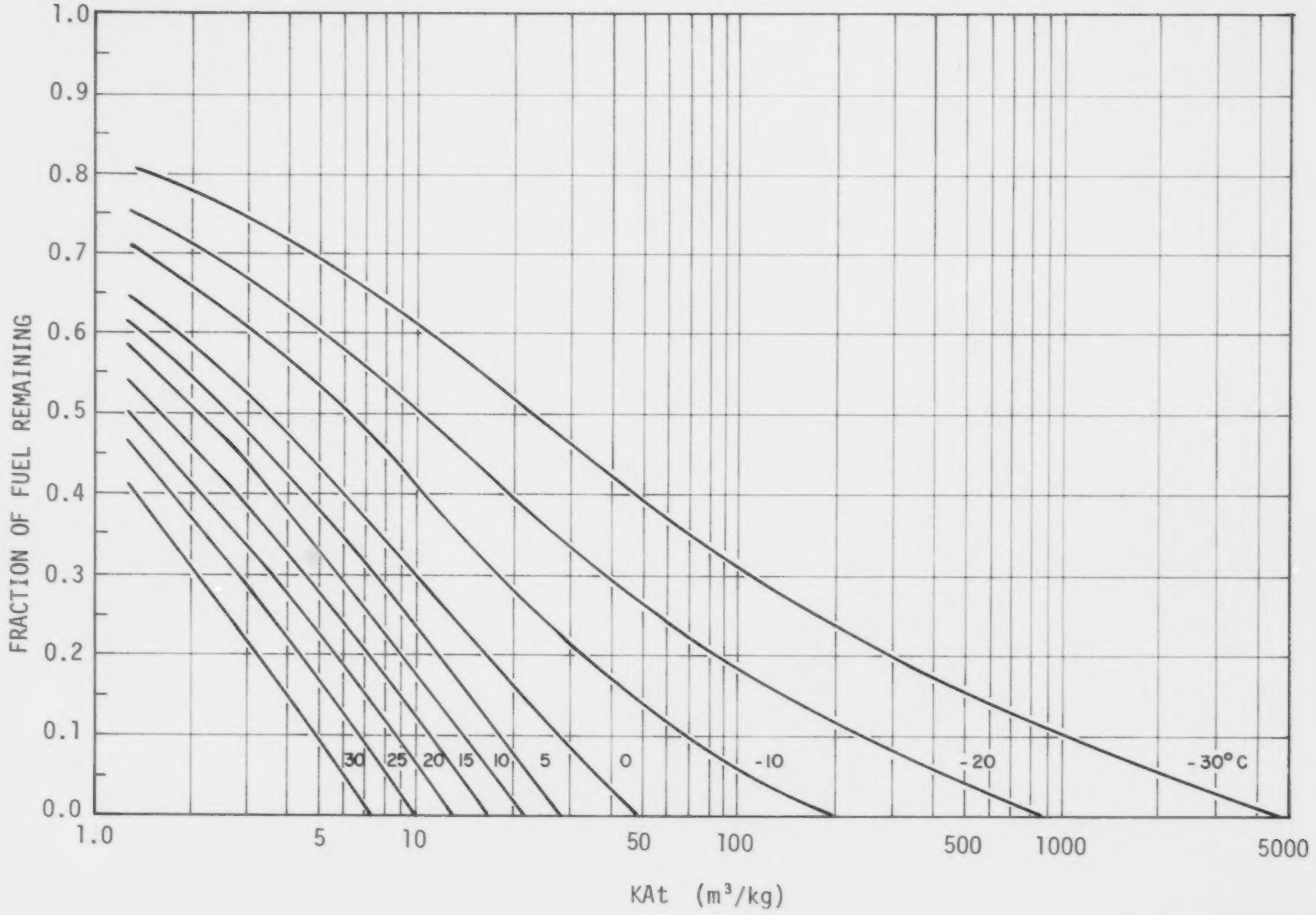


Figure 20. Evaporation curves for summer gasoline (58).

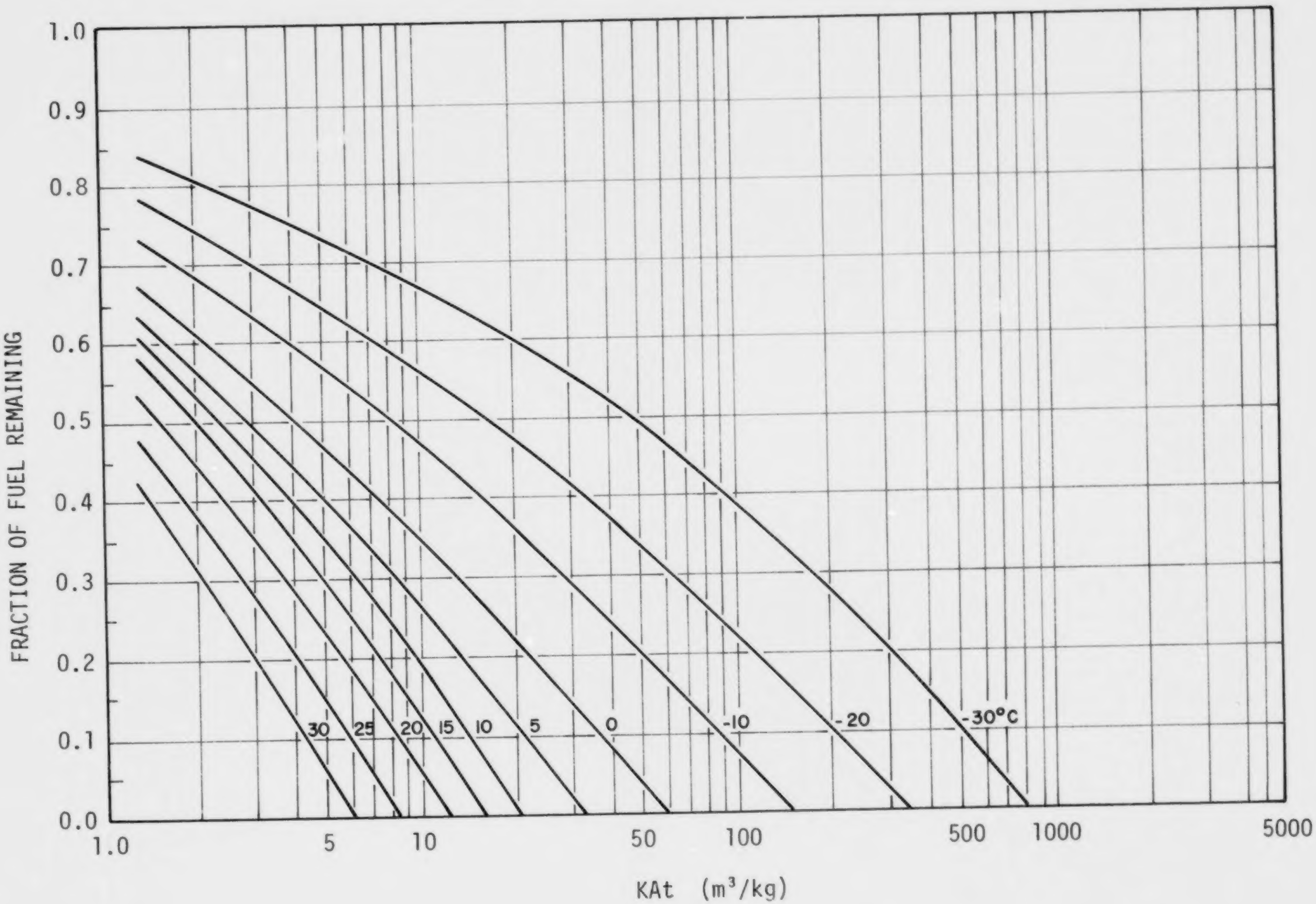


Figure 21. Evaporation curves for winter gasoline (58).

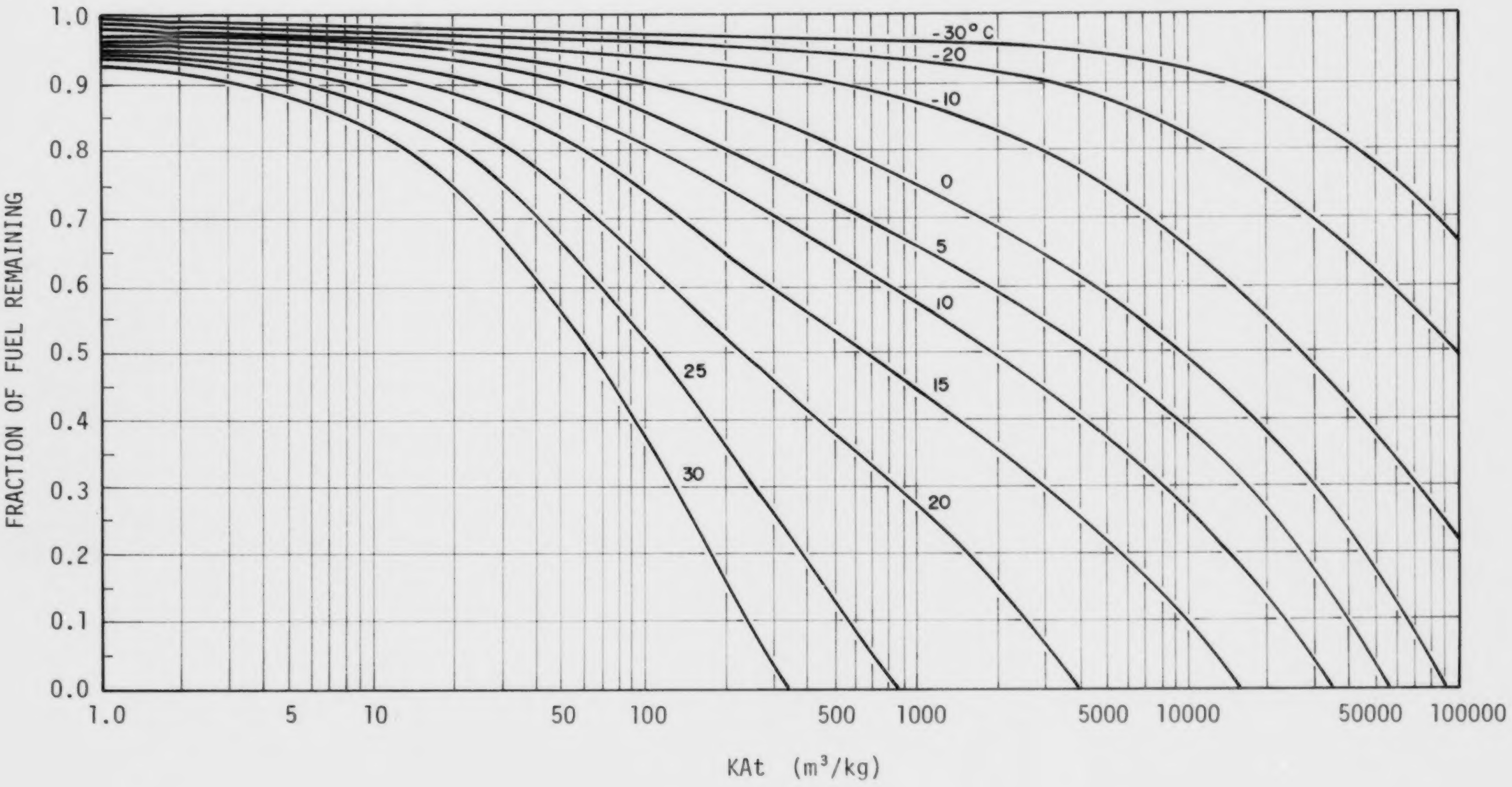


Figure 22. Evaporation curves for winter diesel fuel (58).

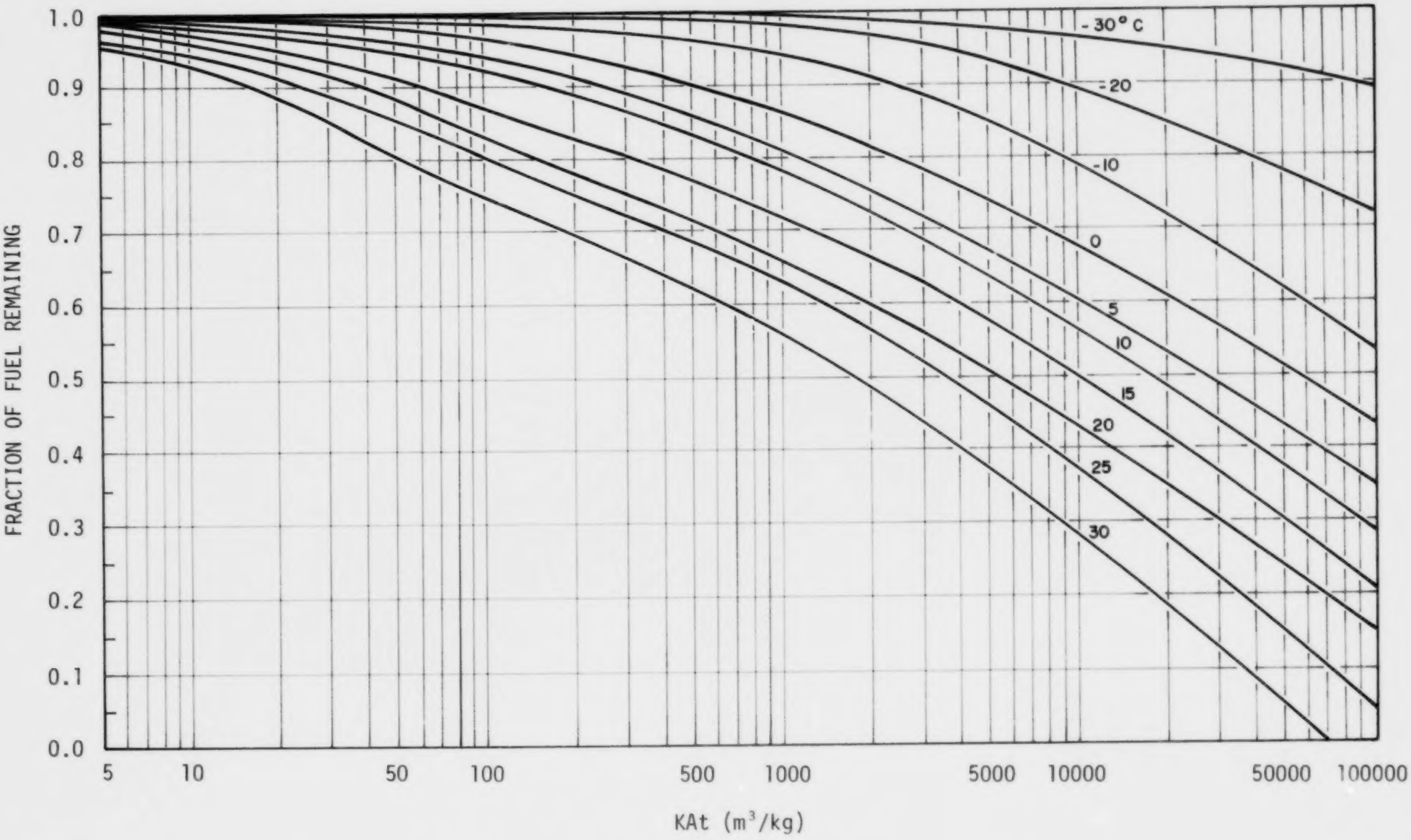


Figure 23. Evaporation curves for summer diesel fuel (58).

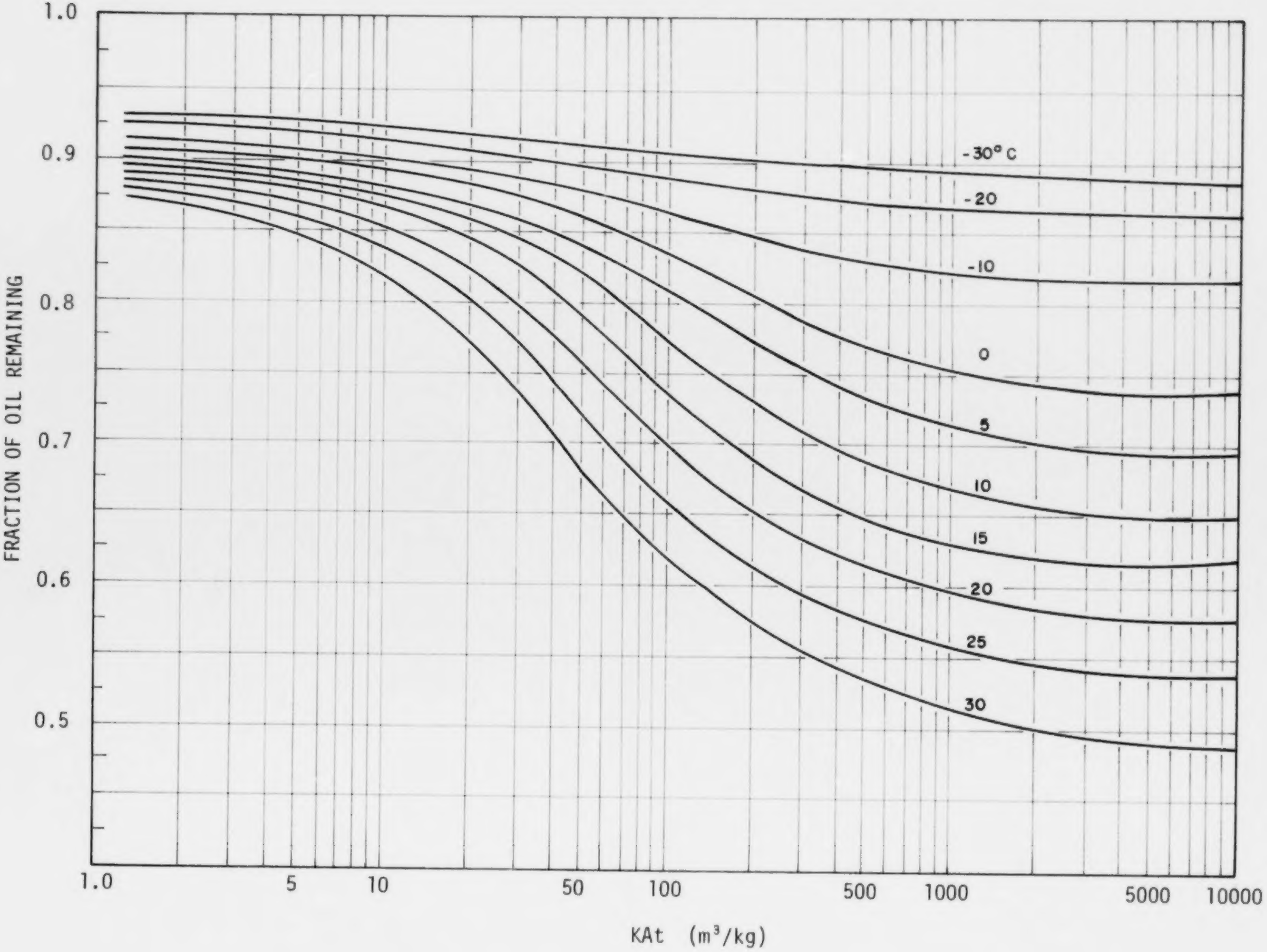


Figure 24. Evaporation curves for light and medium crude oils (58).

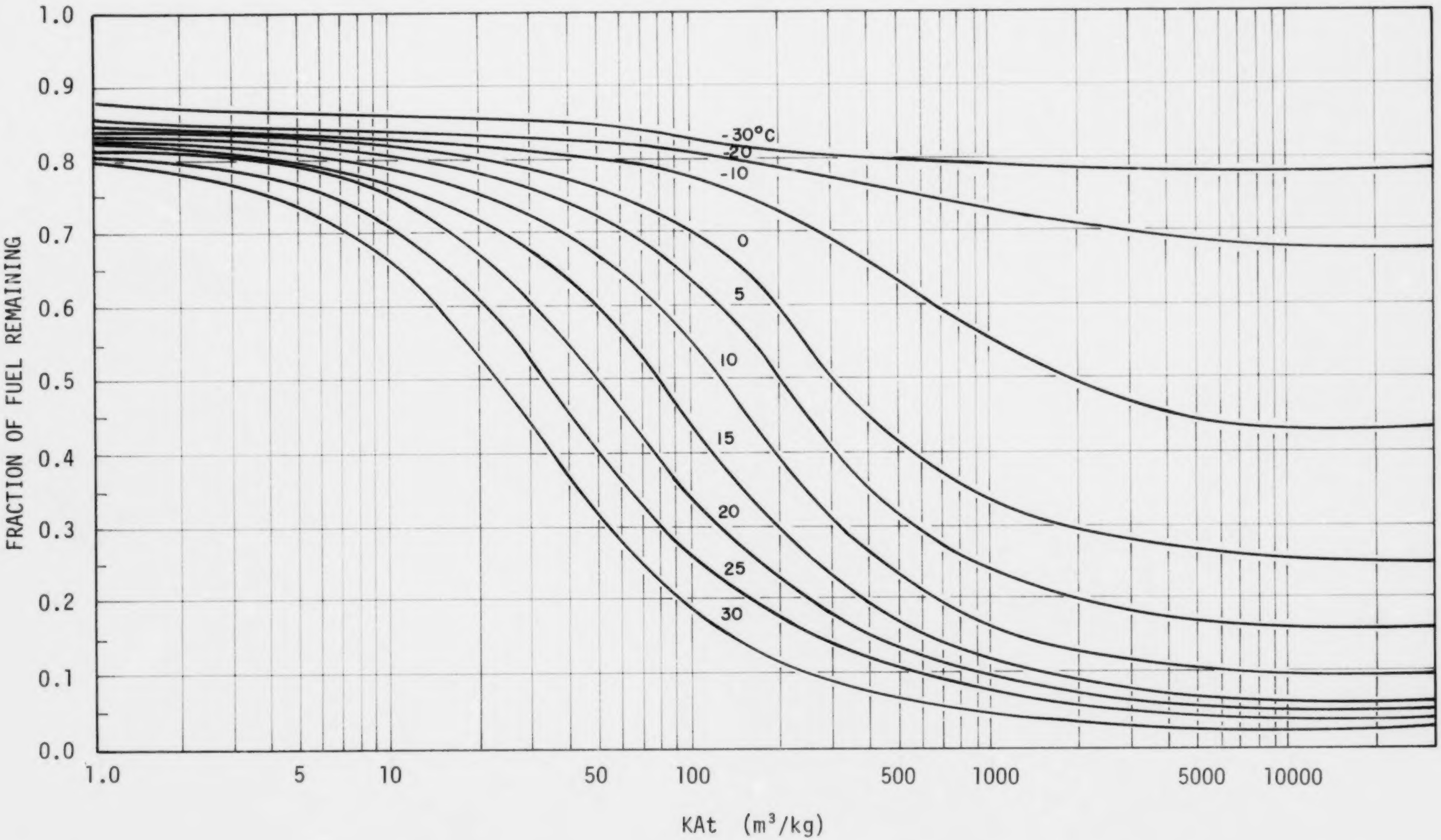


Figure 25. Evaporation curves for Turbo Jet Fuel (A-1) (58).

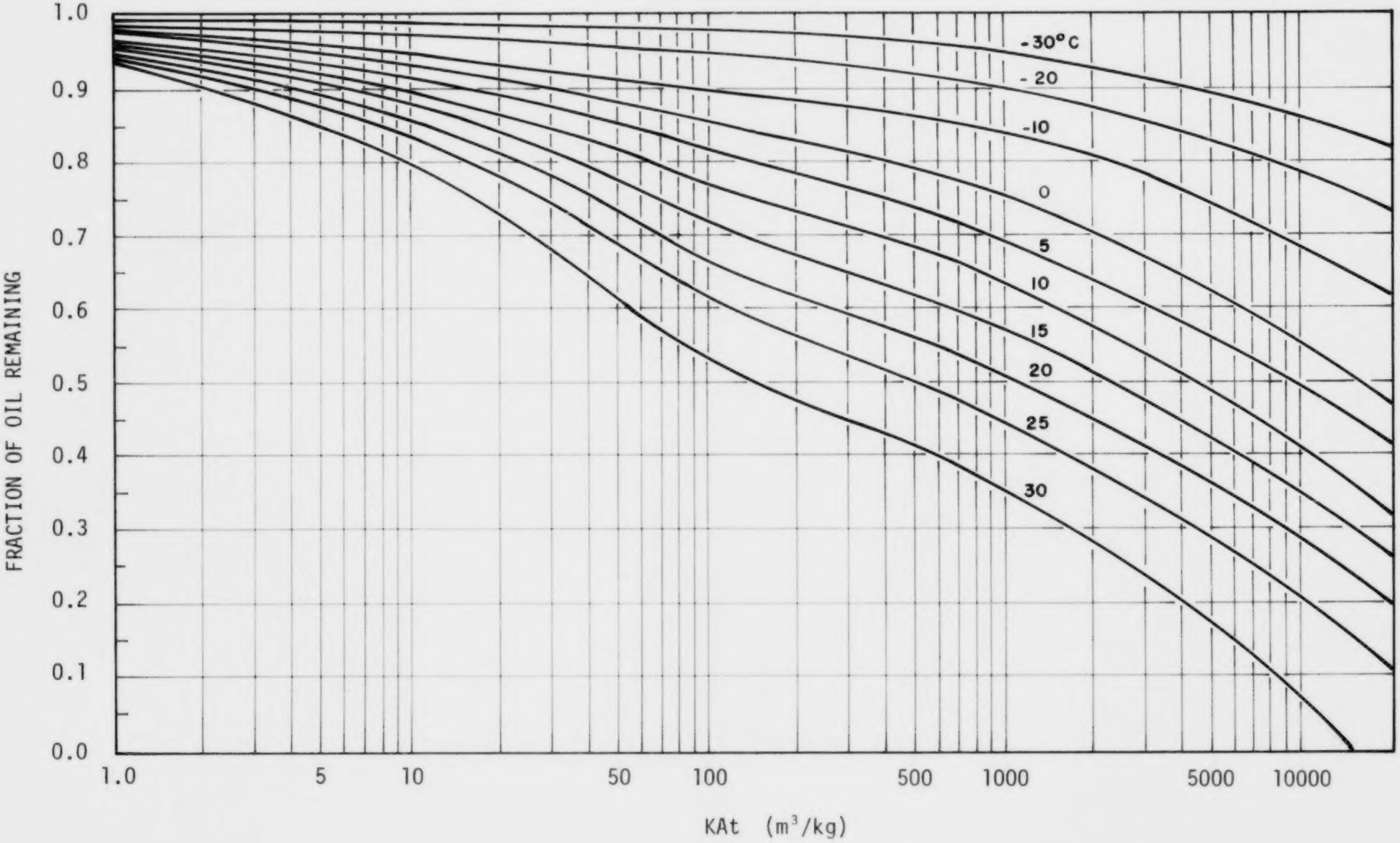


Figure 26. Evaporation curves for No. 2 Heating Oil (58).

SECTION 6

SELECTION OF OIL SPILL SCENARIOS

INTRODUCTION

The purpose of this study is to develop a series of oil spill scenarios for remote inland Alaskan environments that can be used to illustrate a broad range of physical environments and spill situations. Once selected, the scenarios are used as a vehicle to develop the technical details of the study. Selection of the scenarios, therefore, has been the subject of a careful analysis. This section briefly reviews the method that was used in making this selection.

TYPICAL INLAND SPILL SITUATIONS

The spill scenarios were selected to fulfill a number of functions. First, they were to illustrate situations that may occur in a number of typical Alaskan environments. This was accomplished by reviewing sets of typical conditions that may occur based on the environmental conditions described in the Alaskan Profiles contained in Section 4 of this report. Next, the scenarios must represent real spill situations. That is, they must be typical spill situations that occur frequently, or spill situations that could occur in remote Alaskan areas. Selecting spill scenarios then involves two tasks; selecting typical environmental situations and selecting typical spill situations.

Typical environmental situations were developed by reviewing the complete range of environmental conditions that occur in remote Alaskan locations. This was accomplished by listing the various conditions on charts and developing the situations, or combinations of situations, that could occur. Next, the environmental situations in which petroleum development activity occurs, or is likely to occur, were determined. This limited the selection somewhat. To further limit alternatives, and to develop a realistic set of possible spill situations, the scenario alternatives were reviewed with the responsible officials in the field. This was accomplished by making a trip to Alaska to confer with federal and state officials plus interested representatives from industry. These face-to-face meetings with the experienced spill response specialists in Alaska was the key to developing a meaningful, realistic set of spill scenarios. These meetings were used to identify the real, sometimes chronic, spill problems, and situations in which they are likely to occur. The emphasis in selecting scenarios was to identify spill problems that required a solution, and to use this study as a vehicle for helping to solve those problems.

The meetings in Alaska produced a rather long list of scenario alternatives. This list was sifted many times in order to develop a set of scenarios that was typical of real situations and situations that could be used to illustrate a wide variety of response alternatives and environmental conditions. The complete list of possible scenarios was reviewed and eight of the most typical inland oil spill situations were identified. These eight scenarios were reviewed again and a final list of four scenarios was developed for the study.

The paragraphs that follow briefly describe the eight scenarios that were considered as the principal alternatives, and how the final four scenarios were selected.

Blowout

The oil well blowout situation represents both the most hazardous and the most controversial oil spill situation. Blowouts do not occur often, and therefore some knowledgeable Alaskan observers feel that the blowout situation should not be one of the scenarios considered. However, most responsible officials in the Alaskan area do believe that a blowout is a threat, and that this scenario should be considered. In the academic sense, the blowout is a worst-case or limiting spill situation. The blowout also illustrates a number of inland spill response problems that do not occur in other situations. The blowout was therefore one of the scenarios selected for analysis in the study.

Pipeline Spill

Several spills have occurred since the Trans-Alaska Pipeline was put in service. The circumstances under which these spills occurred indicate that some additional spills can be expected in the future. Because of its length, the pipeline covers nearly every available type of Alaskan environment. Selecting a typical pipeline spill environment is difficult; however, this study does include a single, representative pipeline spill scenario.

Tank Truck Spills

In first considering possible spill scenarios, there was a temptation to dismiss tank truck spills as minor and unimportant, being on the level of gas station spills. The situation in Alaska, however, does not support this line of reasoning. First of all, the tank trucks used in Alaska are much larger than those that are typical in the lower 48 states. Thus, the potential for a moderately large spill from a single incident is considerable. Further, the hazards of the road are far greater in Alaska. Severe icing conditions, snow, blowing snow, white-out, and low temperatures are normal winter weather. In addition, most of Alaska is mountainous which increases the driving hazards in severe winter weather. Virtually every spill response official interviewed in Alaska emphasized the importance of the tank truck spills and the high frequency with which they occur. One observer estimated that three such spills could be expected per week during the severe Alaskan weather. Finally, many of these spills occur on roads in remote areas, particularly along the pipeline haul road to Prudhoe Bay north of the Yukon River. It was therefore concluded that a tank truck spill should be included as one of the study scenarios.

Storage Tank Spill

A great many villages located along the Yukon and other navigable rivers are only served by barge traffic in the summer. These villages generally have a central fuel oil storage tank that is filled from the supply barge beached along the riverbank. These servicing operations frequently result in small to moderate sized spills. The fuel lines that distribute the oil from central storage to the users may also rupture or leak and be a source of spills. Although these servicing and distribution spills are fairly common, the village storage tank spill is not included as one of the scenarios. Rather, another scenario that illustrates this and other kinds of fuel distribution problems is substituted.

Airport Fuel Farm Spill

Many remote communities have airports that can be the source of chronic spills. The fuel farm storage tanks and the servicing area may have a number of different spill situations that result in an accumulation of fuel under the storage area. There may be overfill spills while servicing storage tanks, transfer line spills, tank leak spills, and continuing chronic spills that occur in the process of servicing aircraft. This situation can result in an accumulation of oil that may finally move through the ground and cause a continuing spill some distance away. This spill situation is therefore included as a scenario for this study.

Fuel Farm Transfer Line Failure

Fuel farm transfer line failure is a special case that could also be included in a broader category as a storage tank servicing spill or an airport fuel farm spill. Fuel transfer line failures generally occur in the winter and can result from damage of exposed fuel lines by moving equipment, or from natural causes such as a frost jack or permafrost slump. Although these spills are fairly common, the transfer line failure scenario can be included as a part of other spill types and therefore was not selected for inclusion in this study as a separate spill scenario.

Barge Grounding Spills

Barge traffic is an important means of supplying fuel along the Yukon, but there is really no history of oil spills as a result of barge grounding. Barge operations in the Yukon have generally been safe, and if a barge were to ground, the river bottom is generally soft and muddy so that the barge can be refloated without damage to the hull. A spill resulting from a barge grounding was therefore not selected for further consideration in this study.

Railroad Tankcar Spill

A few spills have occurred in Alaska as a result of railroad tankcar derailments, but these incidents are infrequent and the resulting spills have not been large. In addition, since the oil refinery was established near Fairbanks, the use of the rails to haul refined products has decreased. The railroad is used between the refinery south of Fairbanks and the barge terminal at Nenana, but this 97 km (60 mile) trip is relatively safe. Since the general use of the rails to haul oil over long distances is decreasing, it was concluded that the railroad tankcar spill should not be considered further in this study.

Specific spill types and the general environmental conditions have now been selected for the study. The final step will be to select the specific locations in Alaska that can be used to illustrate these conditions.

SELECTION OF SPECIFIC SPILL SITES

The site selections for the four spill scenarios are based upon satisfying the requirements for type of spill and environmental conditions. In some cases, only one location could be found to satisfy all of the requirements previously developed. In other cases several site locations are possible. When more than one site was found to be suitable, the final selection was then based upon the availability of the detailed environmental, geological, and socio-economic data for the given areas. Since the study concerns remote inland areas, a judgement of remoteness had to be made for each candidate site. The remoteness of the site could not be defined in terms of time or distance from major transportation areas, rather the remoteness of the area is considered to be a function of accessibility of the area, ease of travel, weather conditions, quantity of traffic, and the ease of undertaking a response effort in the affected area. The sections that follow describe each site and explain how each fits the scenario requirements.

Scenario No. 1: Exploratory Oil Well Blowout

Most inland drilling is currently occurring north of the Brooks Range in the Prudhoe Bay area where production is now taking place and in the NPRA area to the west of Prudhoe Bay. A blowout scenario in NPRA was selected because of the current exploratory drilling activities there and its relative remoteness in comparison to the Prudhoe Bay field.

The subsections to follow will present the rationale in choosing the general site characteristics for this scenario.

Season--

Most of the drilling in NPRA is done in the winter season because drill depths are commonly 2750 meters or less.

Climate--

NPRA is primarily in the arctic climatological area of Alaska.

Topography--

The topography of NPRA is primarily gently sloping or flat, wet, or moist tundra that is frozen in the winter season. Lakes and rivers are scattered throughout the area, and these are also frozen solid in winter.

Geology--

Continuous permafrost occurs in NPRA.

Ecological Zone--

High brush and seasonally wet/moist tundra dominate NPRA territory.

Oil Behavior--

The oil spill will be a ground surface problem with limited freezing into landscape features. Spill behavior will be a frozen ground problem with gravity movement of oil into local frozen water bodies.

Spill Size and Type--

The blowout scenario will be a large crude oil spill, essentially continuous over a period of days.

Specific Spill Site--

Plans for drilling in the 1980 winter drilling season call for exploration along an arc sixty (60) nautical miles south of Barrow. This area is characterized by numerous ponds, wet to moist tundra, and it is not easily accessible to either ground or air transportation. Since any drilling operation requires a water supply, the drill site must be situated near a major water source, either a large lake or a large stream. The Meade River has been hypothetically selected for this purpose.

Shallow wells will be drilled during the winter. Logistic support will be provided by air on an adjacent ice runway. The ground will be frozen solid with snow cover. Although the blowout is assumed to occur in winter, it may not be checked before spring thaw. Hydrographic data suggests that the Meade River begins to flow in June. If spilled oil spreads to melt ponds or the river, the area affected by the spill will increase substantially.

Scenario No. 2: Pipeline Leak

The Trans-Alaska Pipeline System (TAPS) extends through the entire length of the state with the result that nearly any type of terrain or physical situation is available for selection in a scenario. The scenario selected for this study is a winter pipeline rupture or failure under a riverbed. This particular scenario is of interest because it presents a number of special problems:

- This scenario has not been specifically addressed in current contingency plans.
- The area under the riverbed is likely to have a high potential for thermal effects that may result in pipeline damage.

- A winter spill under the riverbed could result in a moderate to large spill that could go undetected for a long period of time. Presently, the pipeline automatic detection system is not able to detect leaks smaller than 475 m^3 (3000 bbl) per day.

Specific Spill Site--

The Trans-Alaska Pipeline runs about half its course above ground and about half of its course below ground. Experience to date shows that it is most vulnerable in the areas that are below ground. At stream crossings, the pipeline is generally above ground, but in some cases it is below. The case of the pipeline spill below a riverbed has been identified as one that will be difficult to detect, difficult to clean up, and is likely to result in a relatively severe environmental impact. This study will therefore consider the case of a pipeline spill under a stream bed.

In selecting the specific spill site, it is desirable to have a site that is remote. Although all of the pipeline is paralleled by the haul road, south of Fairbanks the pipeline is generally near major highways. To be remote, we are assuming that the site should be north of Fairbanks. Further, to meet other scenario requirements, it is desirable to have an area that is in a continental climate. A site that meets these conditions occurs at the middle fork of the Koyukuk River near Wiseman. The vegetation in this area is upland forest. The spill can be expected to move in the riverbed or under the ice in winter, and therefore detection may not occur until spring breakup. At breakup the oil can be expected to diffuse rapidly in the river because of the high flow rate caused by melt runoff. The high flow of the stream will also contain broken ice which will make response efforts even more difficult. Spilled oil could also spread outside the normal riverbanks because of flooding.

The exact spill site selected is on the southeast bank of the Koyukuk River at pipeline milepost 225.

Scenario No. 3: Airport Fuel Farm Spill

Fuel handling operations at airfields in remote areas commonly result in oil spills. Spills may also result from leaks in deteriorating or damaged storage tanks. As in the previous scenarios, most inland villages associated with the airports are located on navigable rivers south of the Brooks Range. Storage tanks at these airfields may have foundations damaged by frost jack or other thermal effects. They may also leak in areas of undetected rust or from deteriorated or damaged underground transfer lines. In any case, chronic leaks or spills at airfields often go undetected for a period of years with the result that a large amount of product has collected before the spill is detected.

The following paragraphs describe the selection of conditions for this scenario.

Season--

Thermal damage to storage tanks and transfer lines is most likely to occur in the winter season, but these effects may also continue on into the warm months when the active layer and non-frozen soils are permeable. Except for surface spills, detection and cleanup would generally occur during these warmer months when the subsurface oil is more accessible. The summer season is therefore chosen for this scenario.

Climate--

The continental climatic area is chosen for this spill scenario.

Topography--

Most villages in the interior of Alaska are located along major rivers; therefore, a floodplain topography was selected for this scenario. This topography has a characteristic of gentle to moderate ground slopes along the river.

Geology--

Discontinuous permafrost is prevalent in riverside areas. Where they occur, the water table and underlying rock formations will affect oil migration.

Ecological Zone--

Low brush and lowland spruce-poplar vegetate the shoreside area with associated soils and animal life.

Oil Spill Behavior--

In areas where permafrost is not present, oil spilled from a tank leak will slowly migrate into soil until it encounters the water table. Subsurface water flow may carry oil toward streams and rivers. Where permafrost is present, it will limit the downward movement of the oil.

Spill Size and Type--

The spill is likely to be a refined product that is spilled over a long period of time. Airport fuel farms are likely to have a number of moderate to large discrete spills plus more frequent, and perhaps chronic, small spills. In addition, they may have storage tank and transfer line leaks that go undetected for long periods of time.

Specific Spill Site--

Candidate airfields were examined in terms of their size, estimated level of traffic, type of fuel stored, and location. After considering a variety of environmental and physical characteristics, the airport at McGrath on the Kuskokwim River was selected for this scenario. This location was selected because of the variety of the vegetation in the area, the type of soil, and its location on a major river. McGrath could be considered as a major airport for the southwest interior section of Alaska.

Scenario No. 4: Tank Truck Spill

This scenario is intended to show the impact of a tank truck spill in a remote location. Even the well developed highways in the southern part of Alaska are often some distance from populated areas; however, the major highways are generally not considered as remote areas. The pipeline haul road north of Fairbanks may be considered as a remote area. Further, the steep slopes and difficult curves that occur along the haul road in the north make it a likely location for tank truck accidents. The northern segment of the haul road is therefore selected as the general site for the truck spill scenario.

Season--

Although driving conditions are most difficult in winter, spills can and do occur in all seasons of the year. In this case, summer is chosen because it is the most sensitive environmentally.

Climate--

The continental climatic zone is characteristic of the haul road in the remote areas north of Fairbanks.

Topography--

The topography in the area under consideration includes steep vegetated slopes that terminate in small creeks and rivers with an adjacent wetland or bog.

Geology--

The area is underlain by frozen silt, sand and gravel soils with sections having thawed sand and gravel soils.

Ecological Zone--

Vegetation includes low brush-bog and muskeg with upland spruce-hardwood forest in higher areas. The general area of Hess Creek was selected for the scenario because of the steep, winding road in the area and because of its environmental sensitivity, particularly as a habitat for fish. Raptors and waterfowl also use the habitat adjacent to Hess Creek seasonally.

Oil Behavior--

Spilled product may be absorbed by the bog and muskeg, or may drain down into creeks and small streams. Permafrost may limit spreading down into the soil in some areas, but generally steep slopes will cause the spill to move down into drainage areas.

Spill Size and Type--

This spill will be a small instantaneous spill of refined oil product.

Specific Spill Site--

Tank truck accidents can be assumed to occur at almost any location considering the road hazards, possible driver exhaustion, and weather conditions. The segment of the haul road north of Fairbanks between Livengood and the Yukon River has been cited by State authorities as a frequent site of tank truck accidents. The vegetation of this area will make a spill difficult to pick up. Further, Hess creek is important to sport fishing, and the area adjacent to the Creek is a habitat for mammals. Because of these site characteristics, the haul road in the area of Hess Creek has been selected for the tank truck scenario.

SPILL SCENARIO SUMMARY

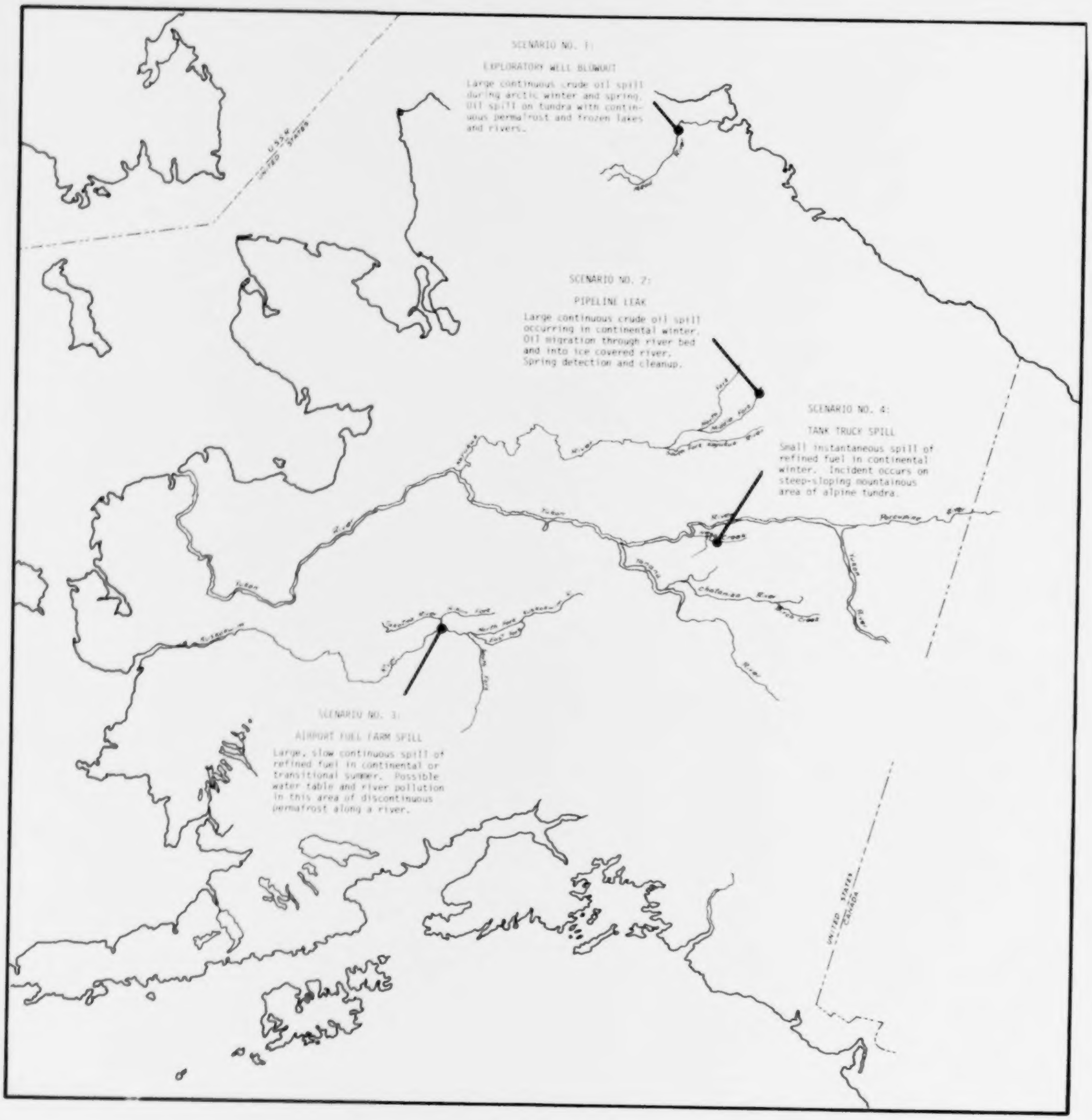
In selecting the spill scenarios for this study, an effort was made to have represented a wide variety of spill types, locations, spill environments, and potential spill impacts. Table 12 provides a summary of the environmental conditions considered for the selected spill scenarios. Table 13 gives a summary of the significant features of the scenarios selected. Figure 27 shows the scenario locations chosen to represent a variety of types of terrain and vegetation in remote Alaskan locations.

TABLE 12 SUMMARY OF ENVIRONMENTAL CONDITIONS CONSIDERED FOR INCLUSION AMONG THE FOUR SCENARIOS

CONDITIONS \ SCENARIO	BLOWOUT	PIPELINE	AIRPORT	TANK TRUCK ACCIDENT
ENVIRONMENTAL				
A) Season				
• Spring	●	●		
• Summer			●	●
• Fall			●	
• Winter	●	●		
B) Climate				
• Arctic	●	●		
• Transitional			●	
• Continental		●	●	●
C) Topography				
• Lakes	●			
• Rivers/Floodplains	●	●	●	
• Mountains/Steep Slopes		●		●
• Foothills	●	●		●
• Plains	●			
D) Geology				
• Discontinuous Permafrost			●	
• Continuous Permafrost	●	●		●
• Basement Rock			●	
• Water Table		●	●	
E) Ecological Zone				
• Wet Tundra	●			
• Moist Tundra	●			
• Alpine Tundra				
• Low Brush-Bog Muskeg			●	●
• High Brush	●	●		
• Bottomland Spruce-Poplar			●	
• Lowland Spruce-Poplar			●	
• Upland Spruce-Hardwood		●		●
OTHER IMPACTS				
• Social		●	●	●
• Economic		●	●	
SPILL BEHAVIOR				
• Open Water	●	●		
• Frozen Ground and Ice	●			
• Snow	●			
• Freezeup				
• Under Ice		●		
• Breakup		●		
• Intragravel		●		
• Soil	●	●	●	●
• Groundwater		●	●	
SPILL SIZE				
• Large	●	●	●	
• Small				●
DURATION				
• Instantaneous				●
• Continuous	●	●	●	
OIL TYPE				
• Crude	●	●		
• Refined		●	●	●

TABLE 13. SUMMARY OF SPILL SCENARIOS

SCENARIO	SPILL SIZE	LOCATION	SEASON	TERRAIN	VEGETATION	SPILL BEHAVIOR
Blowout	50,000 BBL crude	Meade River near Atkasuk	Winter	Lakes, rivers, flood plains, cont. permafrost	Tundra and high bush	Oil on frozen ground, ice, snow, and soil
Pipeline	500 BBL/day for 30 days-15,000 BBL crude	Koyukuk River near Wiseman	Winter	River, foothills, continuous permafrost	High brush, spruce-hardwood	Oil moving under ice, in gravel/ground-water strata, and river at breakup
Airport fuel farm	700 BBL (29,400 gal) stove fuel/JP/gasoline	McGrath	Summer	River, floodplain; discontinuous permafrost	Low brush-bog muskeg, spruce-poplar	Oil moving through soil and along water table
Tank truck	100 BBL fuel oil	Haul road at Hess Creek	Summer	Steep slopes terminating in small creeks	Low brush-bog and muskeg	Oil may be absorbed by the vegetation or may drain down into streams; permafrost may limit spreading down into the ground


U.S.S.R.
UNITED STATES
Yukon
River
Tanana
Chatanika River
Birch Creek
Porcupine River
Yukon River
UNITED STATES
CANADA

SCENARIO NO. 1:

EXPLORATORY WELL BLOWOUT

Large continuous crude oil spill during arctic winter and spring. Oil spill on tundra with continuous permafrost and frozen lakes and rivers.

SCENARIO NO. 2:

PIPELINE LEAK

Large continuous crude oil spill occurring in continental winter. Oil migration through river bed and into ice covered river. Spring detection and cleanup.

SCENARIO NO. 4:

TANK TRUCK SPILL

Small instantaneous spill of refined fuel in continental winter. Incident occurs on steep-sloping mountainous area of alpine tundra.

SCENARIO NO. 3:

AIRPORT FUEL FARM SPILL

Large, slow continuous spill of refined fuel in continental or transitional summer. Possible water table and river pollution in this area of discontinuous permafrost along a river.

Figure 27. Scenario locations.

SECTION 7

OIL SPILL SCENARIO DESCRIPTION

INTRODUCTION

This section describes each oil spill scenario in detail. This includes the details of the spill itself, the spill environment, an analysis of the oil spill behavior, and the problems in predicting oil spill behavior. This section also describes petroleum development, the local population, and the local economy when these factors affect the oil spill problem.

SCENARIO 1 - OIL WELL BLOWOUT

The Spill

The blowout in this scenario occurs during the second week in February on the North Slope of Alaska about 20 km north of Atkasuk on the Meade River. By the first week in March oil has been spilling continuously at a rate of about 5,000 barrels per day for almost three weeks, but capping operations are almost complete. Crude oil from the spill has coated the snow out to a distance of about 1 km from the well. The area near the well has been heavily coated, but only a very light mist is falling near the edge of the area.

A blowout at this exploratory well was not expected. Petroleum geologists had advised drilling teams that there was a low probability of finding oil at this location in the National Petroleum Reserve Alaska (NPRA). Geological investigations also indicated that if oil were discovered, the deposits would be under low pressure. As it turned out, oil was discovered and the pressure was relatively high. The development contractor for NPRA had been drilling for most of the winter months in a flat, lake-dotted area about 6 km northwest of the intersection of the Meade and Nigisaktuvik River. As the drilling reached depths of 2,500 meters, high pressure caused a failure of equipment, including the blowout preventer, sending a geyser about 35 meters into the air. When the blowout was first observed, the oil was spraying up in a fine mist caused by the gas in the well carrying oil droplets to the surface. The prevailing northeasterly winds of about 15 knots carried the finer droplets of oil off the drillpad and onto the snowy tundra. Although some of the very fine droplets were drifting a considerable distance downwind, it appeared that most of the oil was falling within 30 meters of the well.

Equipment available on site was adequate for the initial spill response effort since the major response task could not be launched until the well was capped. The additional equipment needed to cap the well was flown in by C-130 aircraft as soon as the spill was reported. During the capping operation, additional equipment was flown in for the spill response effort that would follow. Although weather delayed the capping operations to some extent, after twenty days and a spill of 100,000 barrels, the oil spill was under control.

The Spill Environment

Except where otherwise noted, all environmental data is taken from the Alaskan Profiles, Section 4 of this report.

Climate--

NPRA is located in the arctic climatic zone. The arctic summers have cool maritime winds, frequent cloudiness, fog, light rain, and continuous light. In winter cloudiness decreases and very cold winds prevail. The sun remains below the horizon for more than two months in the winter. Annual precipitation including both rain and snowfall seldom exceeds 25 centimeters. Low temperatures keep the absolute humidity low, allowing the area to remain wet when it is not frozen. Snow cover is usually present by mid-September, increasing to a depth of 30 to 70 centimeters by March and April. The snow melts by June or July. Winter temperatures average -26°C to -32°C; however, wind chill can result in an equivalent temperature of -46°C or lower.

Surface wind velocity is fairly constant along the arctic plain the year round. At Barrow calm conditions exist only 1.3 percent of the time. The yearly average wind velocity is 11 knots from the ENE and the highest wind velocities of up to 55 knots generally come from the west. Winds in the immediate spill area are predominantly from the NE at about 15 knots. The steady high winds cause considerable drifting and redistribution of the snow.

Topography--

Land Features--The arctic coastal plain is an area of low relief and includes nearly half of NPRA. Topographical relief includes gentle rises that are erosional remnants of ancient wave cut cliffs, fresh and ancient river banks that are generally less than 12 meters high, and pingos, ice cored circular hills. Innumerable thaw lake basins lie as much as 10 meters below the general level of the plain. The principal rivers flowing in the area are the Meade and the Nigisaktuvik Rivers.

The spill area is generally level, with numerous lakes and streams, as shown in Figure 28. There are small rises of dry ground with slopes of one to two meters per kilometer. The drill site is located near a winter trail which cuts through a long dry area on which a runway has been built.

Inland Waters--The hydrology of NPRA is dominated by the cold, dry climate and permafrost. Stream flow essentially ceases in the winter. Most of the annual runoff occurs in the brief two to three week breakup period. Breakup begins in late May when ice jamming and massive flooding occurs on most streams. Ice on deeper lakes frequently does not completely melt until mid-July. Freezeup on water bodies occurs in early to mid-September. During the winter ice has an average thickness of about 2.5 meters.

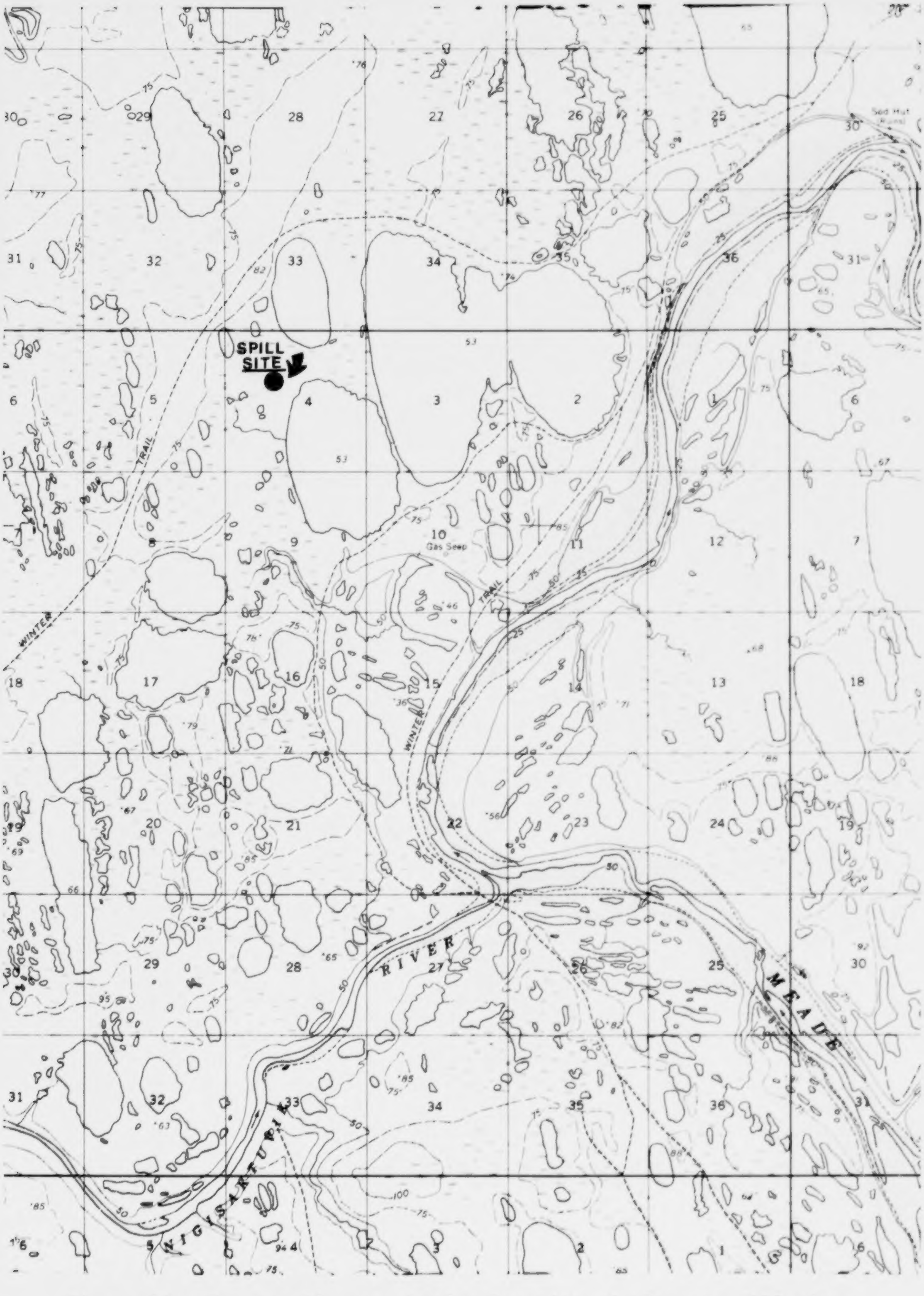

SPILL SITE
Gas Seep
WINTER TRAIL
RIVER
MEADE
NIGISAKTUVIK
Sod Hut Ruins

Figure 28. Topographic map showing location of blowout spill site and topography of the area.

Lakes are the most conspicuous hydrologic feature in NPRA, taking up as much as 40% of the surface area. They range in size from less than 0.4 hectare to 815 square kilometers (81,500 hectares). Generally the lakes have an orientation 10 to 15° west of North. More than half of the lakes sampled have a depth less than two meters and probably freeze to the bottom in winter. Others have depths of 16 to 23 meters. Figure 28 shows some very large lakes located to the east of the drill site, while smaller lakes are situated to the southwest.

Streams and rivers flow through the region in deeply etched channels caused by both hydraulic and thermal erosion of the ice rich silt banks. This leads to undercutting and rapid slumping of the banks, especially during breakup. During spring melt the Meade River flows at 1.6 knots, in the summer the current drops to 0.2 knots. The volume of flow decreases by a factor of 100 between flood and normal flow conditions.

Geology--

Soils in the area vary from poorly drained sand, or sandy loam with a thin peaty surface, to low dunes which are well drained sands. In all cases the ground is underlain by permafrost to a depth as great as 600 meters. The immediate 0.5 to 2 meters at the surface is an active layer which thaws and refreezes annually. Ice content in the permafrost may reach 80% by volume. Any disturbance which results in altering the heat transfer to the permafrost could result in thaw settlement by as much as 60% of its original level. In this scenario the heat transfer disturbance could be a spill of hot crude oil.

Ecozones--

The coastal plain is composed of essentially two types of tundra; wet tundra and moist tundra (59). The wet tundra is essentially a mosaic of small lakes and wet sedge meadows. The peaty soil has a shallow active layer and is saturated throughout the summer. Several species of sedges, especially Carex aquatilis and cotton grass, make up 75 percent of the vegetation. Differences in the vegetative composition are related to the micro relief of the polygons. Many species of mosses grow in the understory, but lichens are abundant only in relatively dry habitats. Secondary species include other cotton grasses, louseworts and buttercupts in wetter sites. Heather, purple mountain saxifrage, dwarf willows, and birch occur in raised drier habitats. Pendent grass is an important species on the shorelines and in the shallow zones of ponds and lakes.

Moist tundra is typified by tussock forming cotton grass. Individual tussocks are typically 15 to 30 centimeters in both diameter and height, separated by troughs 30 cm wide. Secondary species such as grasses, sedges, and dwarf shrubs are scatterd among and on the tussocks. Several different broadleaf herbs also occur. Willows grow along margins of streams to a height of about 1 meter. Lichens are more abundant here than in wet tundra.

In the Coastal Plain Province, the ecological relationships between terrestrial life and freshwater systems are extremely close and complex. Poor drainage, damming effects of snow drifts, and low evaporation rates, cause large parts of the plain to be flooded during early summer. These flooded areas are important for the production of diverse populations of mammals, birds, and fish. These populations constitute the main renewable resource of the NPRA area and supply a significant portion of the food supply to native populations today. About 20 species of terrestrial mammals occur in the NPRA. Of these, grizzly bears, wolverine, caribou, and moose occur in numbers unsurpassed in other Alaskan Arctic areas (59). Dall sheep occur in the southern part of NPRA near the crest of the Brooks Range. Mammals occurring in smaller numbers include wolves, arctic fox, red fox, polar bear, and muskox,

Many species of birds use the NPRA for a breeding ground in the summer. In some cases, a sizable percent of an entire species appear there during breeding season. For example, 27 percent of the North American population of white-fronted geese appear in NPRA in the summer. Other birds using the NPRA area in summer include several species of ducks, loons, whistling swans, shorebirds, gulls,terns, jaegers, ptarmigan, passerines, and several species of raptors. The arctic peregrine falcon is the only endangered species that breeds in the area.

The distribution of fish in the freshwater environment of NPRA is not well known. Nineteen species of fish have been identified in the area; however, ice on lakes and streams reduces the overwintering habitat. As a result, fish are restricted to those lakes and rivers that do not freeze to the bottom in winter. During open water season fish are most likely to inhabit waters that have inlets, outlets, and an adequate depth for spawning.

Economy--

Subsistence has been a proven means to ensure survival on the arctic slope. Between economic boom eras associated with commercial whaling, fur trapping, and military and petroleum development, the only consistent means of survival has been subsistence. Subsistence provides food, particularly meat, and other items for clothing and shelter. Even today there are no community stores which could provide all the basic supplies or food necessary for survival. Cash alone cannot support the native communities.

On the other hand, cash employment is now a necessary counterpart to subsistence. This is because current subsistence practices involve substantial outlays of cash for rifles, traps, boats, snow machines, and other equipment. This induces residents to split their time between subsistence and wage employment. A common life pattern is for a wife to seek employment while the husband devotes the greater part of his time to subsistence related activities.

The composition of the employed sector involves two identified populations, native residents and non-native immigrants. Generally, non-natives fill more highly skilled jobs associated with social services or industrial projects. Natives have been employed intermittently for general labor. The labor force characteristics from the Barrow area are shown in Table 14 (59).

TABLE 14. LABOR FORCE CHARACTERISTICS, BARROW LABOR AREA[1]

	1970	1971	1972	1973	1974	1975	1976
Civilian resident labor force (annual average):							
Percent of labor force	11.0	13.7	11.8	9.9	8.1	6.0	3.6
Range	6.1-18.8	7.2-21.3	7.3-18.5	6.2-13.4	5.5-10.4	5.1-9.5	2.0-5.1
Total unemployment[2]	99	113	102	97	115	114	174
Total employment	794	709	765	877	1,299	1,299	4,627
Total	893	822	867	974	1,414	1,413	4,801
Nonagricultural wage and salary employment by place of work (annual average):							
Mining (petroleum-related)	280	119	117	103	290	2,611	1,271
Contract construction	137	104	70	119	380	3,738	-
Manufacturing	(3)	0	0	0	0	(3)	(3)
Transportation, communications, public utilities	86	80	95	168	145	185	316
Trade	(3)	(3)	(3)	(3)	(3)	129	(3)
Finance, insurance, real estate	(3)	(3)	(3)	(3)	(3)	56	(3)
Service	142	150	175	187	96	196	445
Miscellaneous	0	0	0	0	0	(3)	0
Government:							
Federal	128	168	173	171	283	265	239
State	37	114	161	224	358	525	652
Total	977	848	913	1,052	1,450	1,997	6,932

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[1] Coextensive with the 1970 Barrow census division. Prior to 1976, the Barrow labor did not include the Prudhoe/Deadhorse area.

[2] Does not include those who are unemployed for many reasons, including physical handicaps, those whose unemployment benefits have been exhausted, or those who were never covered by unemployment benefits.

[3] Withheld to comply with disclosure regulations.

Transportation--

In NPRA transportation routes by air, waterways, and over land connect villages, bases, and population centers such as Fairbanks and Anchorage. However, the land transportation network is rudimentary.

Major public air facilities in or near NPRA are located at Barrow and Deadhorse. Barrow has a 6500 ft asphalt runway equipped with approach lights and can handle large aircraft such as the C-130 and the Boeing 727. Deadhorse also has a 6500 ft asphalt strip with approach lights and runway center lights. Both of these airfields have standard aviation fuels available. In the interior of NPRA, Meade River has an unmarked 1200 ft grass air strip. Runways are always developed at drilling sites. If the well is shallow and will be completed in one winter season, only an ice runway is constructed. Year-round drilling sites call for the construction of permanent runways built over insulation and thick gravel to protect the permafrost. These runways are adequate for a C-130 aircraft.

Overland travel in NPRA is limited to the winter months when the tundra is frozen. Tracked or low ground pressure vehicles can then be used to transport equipment, personnel, and supplies to interior locations. Typically these vehicles are arranged in the form of trains using a tractor pulling several loaded sleds.

Population and Society--

The native population of the north slope is Inupiat, a subdivision of the Eskimo. The Inupiat have broken into two complementary adaptations, the Tareumiut,or people of the sea, and the Nunamiut, or people of the land. The Tareumiut depend primarily on products of the sea for survival. The Nunamiut are nomadic, following the migrations of caribou throughout the northern Alaska region. These two groups are viewed as different expressions of the same culture. Their hunting specializations represented a division of labor that allow full use of the area's diverse resources.

The population and settlement patterns in the arctic slope region are affected by two underlying factors. First, the increase in resident population is largely due to an increase in the Eskimo birthrate and greater life expentancy, plus an influx of social services and white collar personnel. Second, seasonal work patterns are modified by available market goods and cash jobs.

Barrow's population grew 500 percent between 1939 and 1970, and its population now exceeds 2000. Three traditional native communities were re-established during the 1970's; Atkasook (Meade River), Nuiqsut, and Point Lay. These communities have a combined population of about 300 consisting mainly of immigrants from Barrow seeking to return to a more traditional way of life. Table 15 shows the population distribution throughout the NPRA region (59).

Petroleum Development

Surface exploration began in the National Petroleum Reserve in Alaska in 1904 and geologic exploration has continued sporadically to the present

TABLE 15. POPULATION ESTIMATES, NORTH SLOPE BOROUGH REGION, 1939-77

[Source: U.S. Census; North Slope Borough]

Community	1939	1950	1960	1970	Jan. 1974	Jan. 1975	July 1975	Dec. 1975	July 1976	Jan. 1977	July 1977
Traditional communities [1]											
Anaktuvuk Pass		66	35	99	134	134	129	129	150	150	151
Atkasook (Meade River)	78	49	30	-	-	-	-	-	-	-	86
Barrow	363	951	1,314	2,152	2,163	2,163	2,141	2,107	2,294	2,294	2,220
Kaktovik	13	46	120	123	141	141	119	119	123	123	134
Nuiqsut	89	-	-	-	145	149	149	149	152	152	157
Point Hope	257	264	324	386	404	404	384	403	408	408	412
Point Lay	117	75	-	-	27	27	48	48	51	51	54
Wainwright	341	227	253	315	354	354	341	344	357	394	398
Subtotal	1,258	1,678	2,076	3,075	3,368	3,368	3,311	3,299	3,535	3,572	3,612
Oil and gas/pipeline camps:[2]											
Prudhoe Bay/Deadhorse Area	NA[3]	NA	NA	279	927	3,158	5,022	5,531	8,801	7,765	5,318
NPRA	NA	NA	NA	3	5	5	5	5	55	505	33
Subtotal				282	932	3,163	5,027	5,536	8,856	8,270	5,351
Military stations:[4]											
Cape Lisburne	-	-	NA	83	112	112	112	112	112	112	92
DEWLINE	-	-	NA	111	111	111	111	111	111	111	108
Subtotal				194	223	223	223	223	223	223	200
TOTAL				3,551	4,523	6,754	8,561	9,058	12,614	12,065	9,163

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[1] Population for traditional communities since 1970 based on actual counts or Borough Planning Department estimates. The estimates for Barrow appear low. In the opinion of Alaska Consultants, Inc., the community's population was at least 2,700 persons.

[2] Population for oil/gas and pipeline camps since 1970 provided to the North Slope Borough by industry groups. Estimates for NPRA from January 1974 through December 1975 provided by the U.S. Geological Survey.

[3] Not available.

[4] Population for Cape Lisburne since 1970 provided to the North Slope Borough by the U.S. Air Force. Population for DEWLine stations (excluding POW-Main) provided to the North Slope Borough by the U.S. by FELEIC Services, Inc. for the period December 1975 through July 1977. DEWLine populations back through 1970 assumed by Alaska Consultants, Inc. to be at December 1975 level.

time. The area was officially known as Naval Petroleum Reserve No. 4 beginning in 1923 and complete mapping of the area systematically proceeded from that year until 1926. From 1944 to 1953 extensive geological and geophysical surveys were made and 36 test wells were drilled in the region. These test wells discovered oil at Unimak and gas at Gubik and Barrow. Possible gas fields were noted at Meade River, Square Lakes, and Wolf Creek. Two minor oil deposits were discovered at Sampson and Fish Creek. Several wells have since been drilled around Barrow to supply the town with gas. The Navy drilled two oil wells in 1975, one in 1976, and six in 1977. The U.S. Geological Survey drilled seven exploration wells in 1978 and six in 1979.

Immediately adjacent to NPRA, private oil companies have drilled six wells near Unimat, two in the Kurupa and Killik River areas, and three in the lower Colville River regions.

The study of geological features in the Prudhoe Bay area, which is the largest proven petroleum reserve in North America, suggests that hydrocarbon accumulations of similar magnitude may not exist anywhere else on the North Slope. Nevertheless, smaller accumulations can be found; therefore the Department of Interior is expanding the original work of the U.S. Navy and is drilling four to six shallow (<4500 m) depth wells each winter and two deep wells to 5800 m each year.

Oil Spill Behavior

The oil well blowout in this scenario is a crude oil spill of approximately 5,000 BBL per day from a high pressure well with high gas content. This spill rate is assumed as characteristic of a moderate sized blowout typical of a smaller petroleum deposit than would occur at Prudhoe Bay.

A search of the literature to establish oil spill behavior did not yield a detailed description of an oil well blowout on land. Information sought, but not found, included a means of determining the height of the oil geyser, the droplet size, and the way the oil may be deposited on the ground. The purpose of this engineering analysis, then, is to estimate these conditions and develop a description of the distribution of the oil at the spill site at the time the blowout has been secured. The analysis begins by calculating the height of the oil droplets in the plume.

Much of the oil released from a high pressure well will emerge in the form of a mist or spray. To project the behavior of this spray, it is assumed that all of the oil reaches a geyser height above the well after leaving the ground. At this point, the oil feels the effect of the wind and is carried away from the wellhead. The height of the geyser is a function of the reservoir pressure and the exit pressure. Using a subsurface well pressure of 845 kg/cm^2 (12,000 psi) and a ground level oil exit pressure of 70 kg/cm^2 (1,000 psi), the velocity of the oil upon leaving the ground is calculated by the Darcy-Weisbach expression:

$$\frac{P_{\text{oil}} - P_{\text{ground level}}}{\gamma_{\text{oil}}} - \frac{P_{\text{hydrostatic}}}{\gamma_{\text{oil}}} = f \frac{L}{8R_h} \frac{V^2}{g}$$

where

P_{oil} = oil pressure in the oil deposit = 845 kg/cm^2 (12,000 psi)
$P_{\text{ground level}}$ = oil pressure at ground level = 70 kg/cm^2 (1,000 psi)
$P_{\text{hydrostatic}}$ = hydrostatic pressure necessary to raise a column of oil to ground surface = 240 kg/cm^2 (3,380 psi)
γ_{oil} = specific gravity of oil = 0.95 g/cm^3 (1.89 slugs/ft^3)
f = Darcy-Weisbach friction factor = 0.02 for cast iron pipe
L = length of drill hole = 2,500 m (8,200 ft)
R_h = hydraulic radius of pipe = 1/4 diameter = 0.08 m (0.25 ft)
V = velocity of moving oil
g = acceleration due to gravity = 0.8 m/sec^2.

Using this relationship, the velocity of the oil at ground level is calculated to be 26.6 m/sec (87.3 ft/sec). Using a total energy exchange and assuming no additional energy losses, the geyser has zero relative velocity at a height of 34.4 meters (112.9 ft), which is the maximum height of the geyser.

Having established the vertical height of the geyser, one may then determine the horizontal dispersion of the oil droplets as a function of how quickly the oil can fall back to the earth. Large drops will fall quickly, landing close to the source. Small drops can reach terminal velocity before hitting the ground and can consequently be carried farther by the wind. In calculating the horizontal distance that the oil travels before striking the ground, the system can be viewed as a point source of oil located at the top of the geyser in a uniform wind. Initially all droplets undergo a constant acceleration during the fall from the geyser, with smaller droplets reaching a terminal fall velocity before hitting the ground. Allowing for this terminal velocity, the horizontal distance any particle travels can be calculated from the following equation:

$$D_H = V_o t_T + V_o \left(\frac{h - 1/2 g t_T^2}{V_T} \right)$$

where

D_H = total horizontal traverse of any oil particle
t_T = falling time until the particle reaches terminal velocity
V_o = wind speed (assume 15 kts or 7.73 m/sec)

h = height of oil geyser (34.4 m or 112.9 ft)
g = acceleration due to gravity
V_T = terminal velocity of a given droplet.

In this expression, $V_o t_T$ represents the horizontal distance a particle travels before reaching terminal velocity, and the second term represents the distance a particle travels after reaching terminal velocity.

The time to terminal velocity, t_T, is simply calculated by

$$t_T = \frac{V_T}{g} \ .$$

At terminal velocity, it is assumed that all oil particles satisfy Stokes flow requirements; i.e., the particle Reynolds number ≤ 5. The terminal velocity is then given by (60):

$$V_T = \frac{2}{9} \frac{a^2 g}{\mu_a} (\gamma_{oil} - \gamma_a)$$

where

a = oil droplet radius
μ_a = absolute viscosity of air (180.2 μPoise)
γ_{oil} = density of oil (0.95 g/cm^3)
γ_a = density of air (1.293 x 10^{-3} g/cm^3)

Substituting for t_T and V_T into the horizontal distance equation,

$$D_H = \left(\frac{V_o}{V_T}\right)\left(\frac{V_T^2}{2g} + h\right)$$

$$D_H = V_o \left(\frac{a^2 \gamma_d}{9\mu} + \frac{9h\mu}{2a^2 \gamma_d g}\right) = \text{Reynolds Number} \leq 5$$

where $\gamma_d = \gamma_{oil} - \gamma_a$. Figure 29 provides a plot of this equation showing distance traveled versus drop radius for two different wind speeds.

Based on the Stokes flow assumption, the smallest droplet of oil that hits the ground without reaching terminal velocity has a particle radius of 0.252 mm. Particles having larger radii will have returned to the ground in a shorter distance.

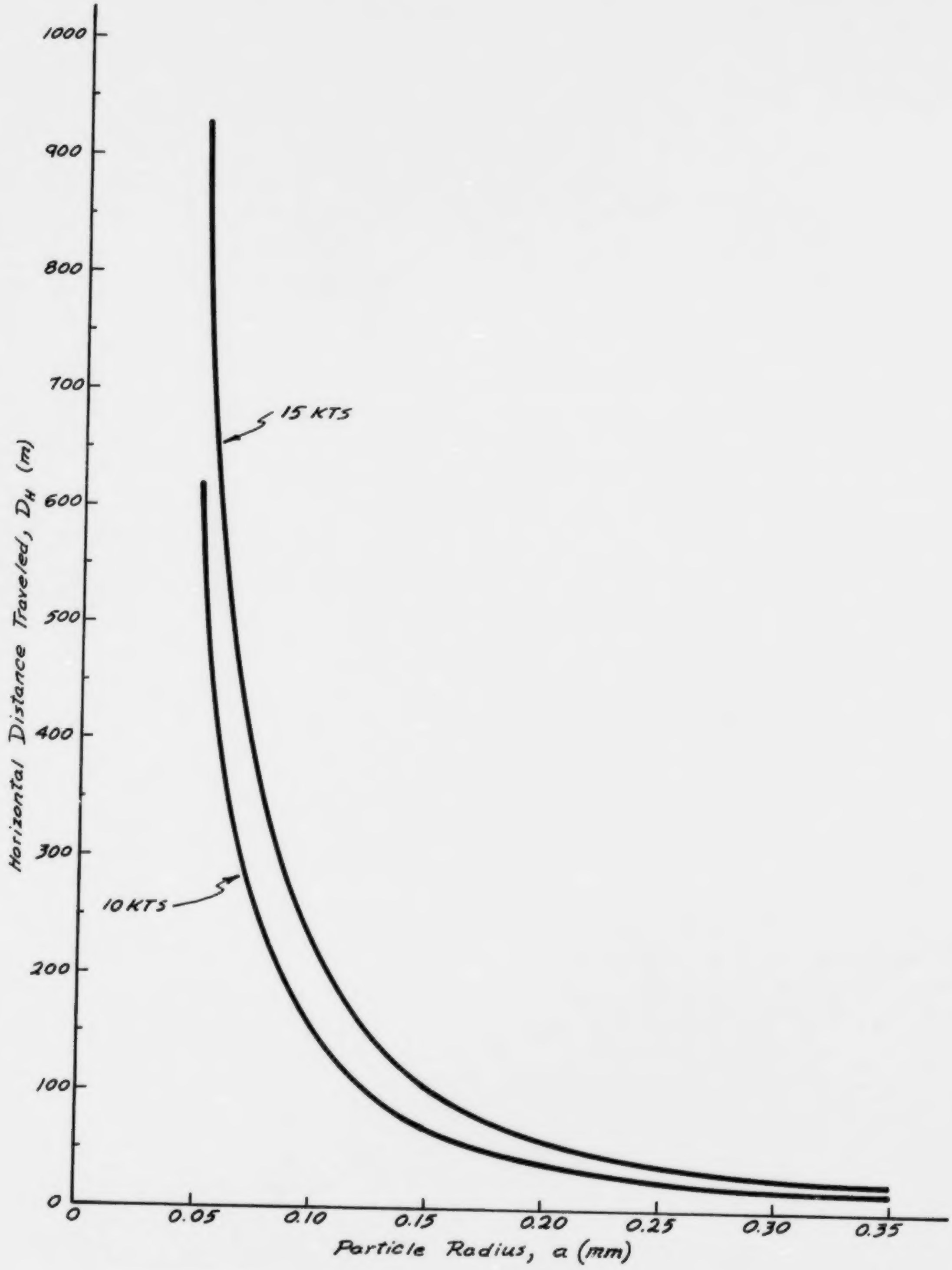


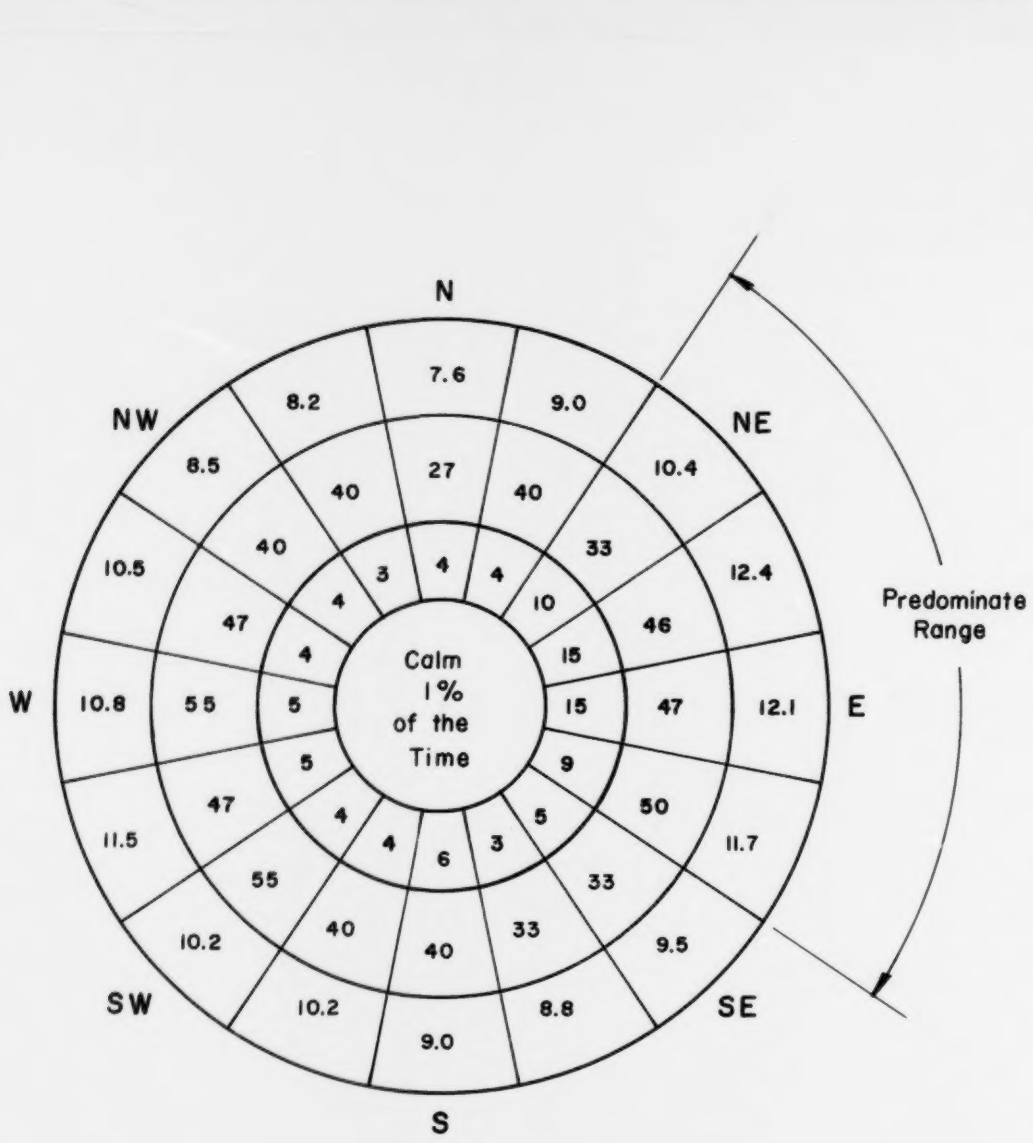
Figure 29. Oil particle radius versus horizontal distance.

Figure 30 shows that in winter winds blow from the sector between NE and SE 50% of the time (3). Using this information, it is assumed that a 90° wedge between NW and SW contains 50% of the oil spilled and the remaining area is covered by the other 50% of the oil.

The average quantity of oil spilled in these areas is calculated using the drop size distribution shown in Figure 31. Lacking better information, the droplet size distribution was taken as similar to one determined by Topham for an underwater blowout (61). Since this blowout is in air, the drop sizes were assumed to be half as large. Referring to Figure 29, a wind speed of 15 knots will carry a drop of radius 0.05 mm out to 928 m from the well head, a drop of radius of 0.12 mm will land about 152 m from the well, and all droplets greater than 0.2 mm in radius will fall on the drill pad and be contained inside the berm, which is approximately equivalent to a radius of 61 m. This study uses a wind speed of 15 kts, which is conservative since it is higher than the average for any given sector. Figure 29 shows that for 10 kts of wind, which is closer to the average for each sector, the maximum distance that fine particles are transported is much less than for 15 kts. For the larger particles, the distance traveled is about the same. Since the highest frequency of particle size is assumed to be 0.5 mm, one may conclude that the pattern of heavy deposits of oil will not be changed much by wind, but that in very high winds, the finest particles may be transported a considerable distance.

Figure 32 shows the average thickness of oil in each region around the well after 20 days. The oil, of course, will not remain in these thicknesses; it will flow, while it is fluid, to lower ground and into the sand and gravel drilling pad. Most of the oil estimated to fall on the drill pad downwind from the well will fall or flow into the reserve pit which is always constructed in the predominantly downwind area. Figure 33 shows a typical drill pad configuration (62). NPRA operators report that crude oil spilled in mid-winter, as in this scenario, will set up and harden into a solid in two to three hours. Therefore, oil flowing into the reserve pit and all oil in other areas around the well in this scenario can be expected to harden quickly. The high temperature of the oil leaving the well is expected to have little effect on oil behavior because the cold air temperatures quickly dissipate the heat. The oil spilled on the drilling pad will seep into the gravel, but the cold temperatures and frozen ground are expected to slow and eventually stop this vertical movement. Lighter oil particles carried beyond the drill pad boundaries are expected to harden during their fall and appear as brown "sleet" as they strike the ground. The smallest of these will continue to be carried by the wind with blowing snow. The albedo of areas coated with oil is raised significantly and, therefore, adequate cleanup is necessary to avoid unnatural thawing of the active permafrost layer of the tundra.

The gas and evaporation of the lighter ends of the crude oil present an explosion and fire hazard in the immediate area of the blowout. The escaping gas may not be toxic to breathe, but could cause suffocation to personnel not equipped with special breathing apparatus. Because of the hazards to personnel in the area, a spill cleanup effort cannot be launched


N
NE
E
SE
S
SW
W
NW
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9.0
10.4
12.4
12.1
11.7
9.5
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9.0
10.2
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4
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15
9
5
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6
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4
5
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4
4
3
Calm
1%
of the
Time
Predominate
Range

Figure 30. Winds at Point Barrow. The inner circle shows the percent frequency of winds from the indicated direction. The middle circle shows the maximum wind and the outer circle shows the average wind (3).

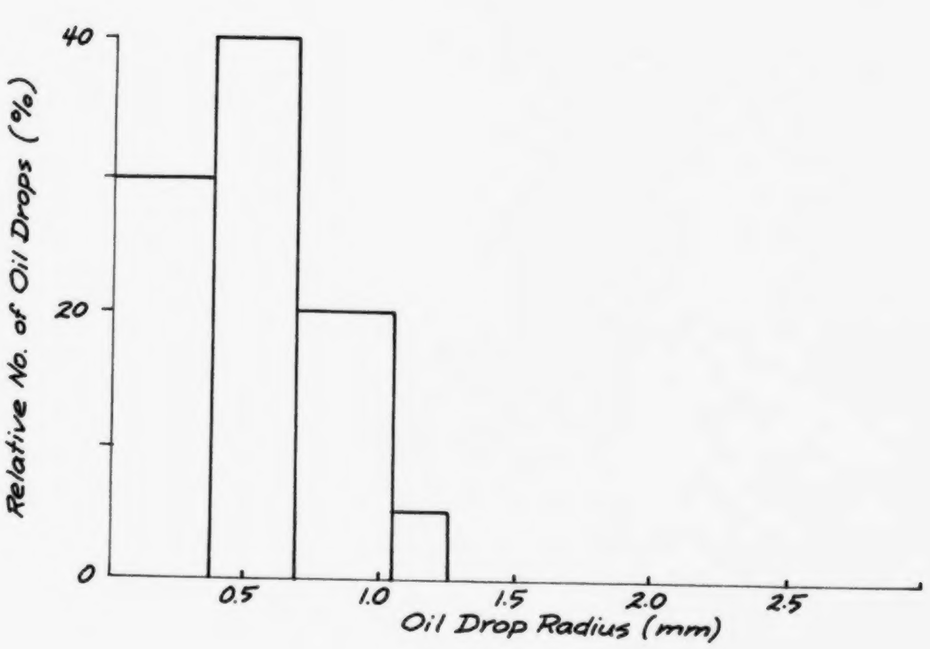


Figure 31. Blowout droplet size distribution (61).

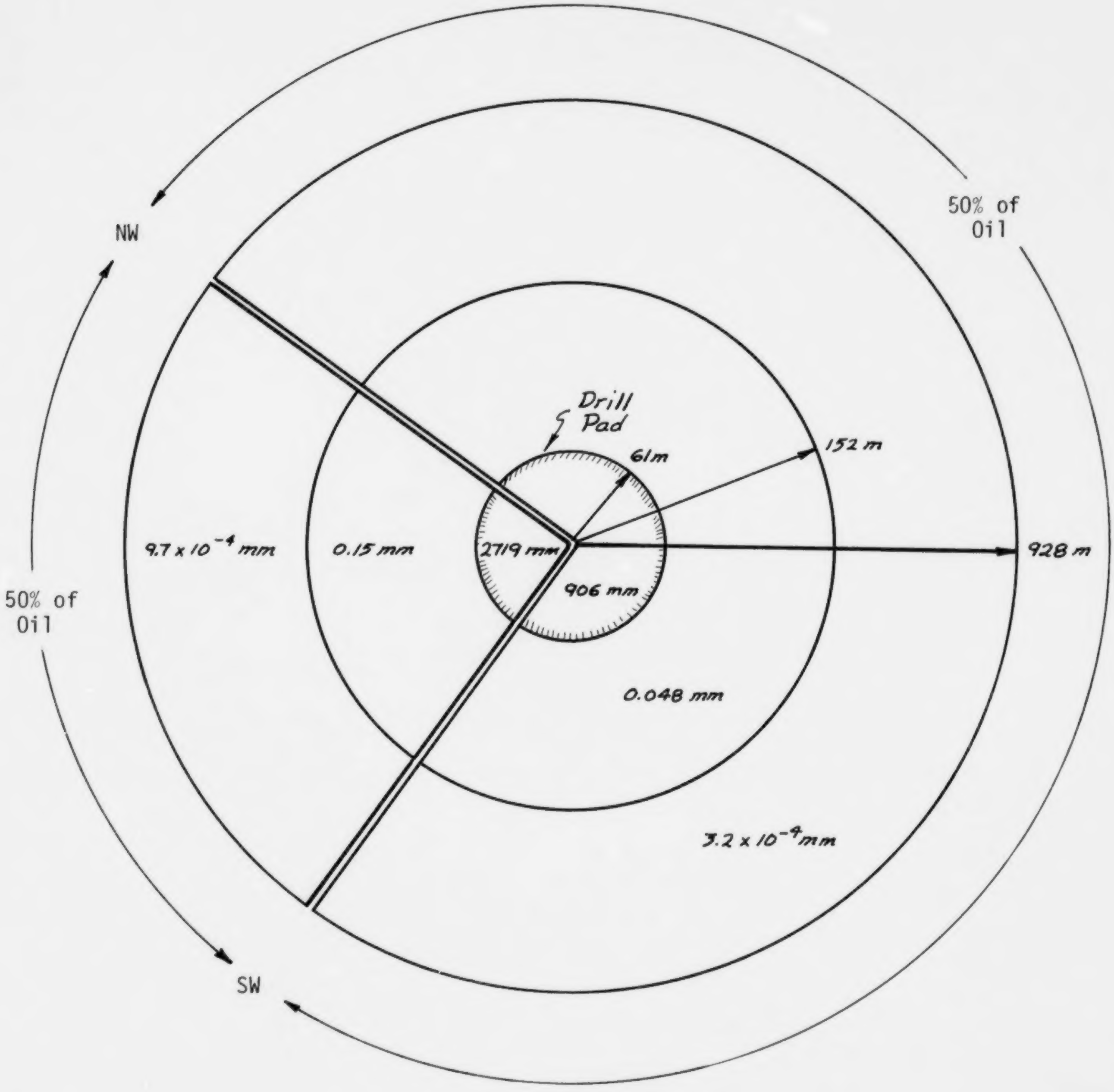
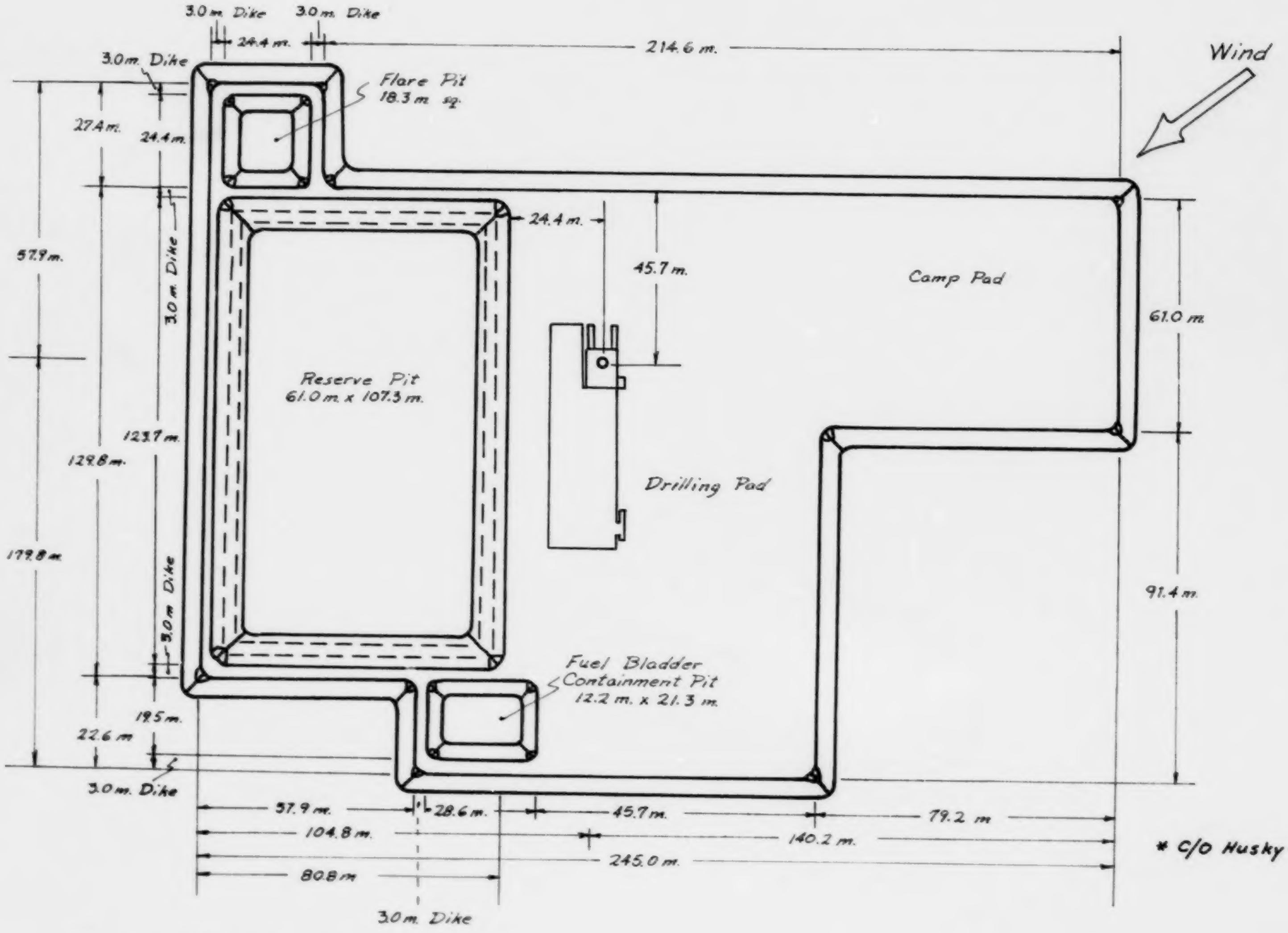

50% of Oil
NW
Drill Pad
61m
152 m
9.7 x 10^-4 mm
0.15 mm
2719 mm
928 m
906 mm
50% of Oil
0.048 mm
3.2 x 10^-4 mm
SW

Figure 32. Average thickness of oil around the well after 20 days.


Wind
214.6 m.
3.0 m. Dike
3.0 m. Dike
24.4 m.
3.0 m. Dike
Flare Pit
18.3 m. sq.
27.4 m.
24.4 m.
57.9 m.
3.0 m. Dike
Reserve Pit
61.0 m. x 107.3 m.
123.7 m.
129.8 m.
179.8 m.
3.0 m. Dike
19.5 m.
22.6 m
3.0 m. Dike
24.4 m.
45.7 m.
Camp Pad
61.0 m.
Drilling Pad
91.4 m.
Fuel Bladder
Containment Pit
12.2 m. x 21.3 m.
57.9 m.
28.6 m.
45.7 m.
79.2 m
104.8 m.
140.2 m.
245.0 m.
80.8 m
3.0 m. Dike

* C/O Husky Oil Co.

Notes:
1. Nominal Pad Thickness is 1.5 m.
2. Dike and Pad Side Slopes approx. 3:1.
3. Depth of Reserve Pit from Pad Surface is 3.0 m., Including 1.5 m. Excavation into Original Ground.
4. All-weather Pad Will be Constructed of Appropriate Fill Compacted to Withstand Winter Travel. Where Necessary to be Consistent With Winter Construction, Compaction Will be 95 % Mod Proctor.

Figure 33. Typical drill pad dimensions.

until the well has been capped. Some response effort may be permitted some distance from the blowout, particularly in the upbound sector. For example, diesel driven scrapers may be used at a safe distance from the blowout to construct snow berms to restrict the oil from spreading while it is still fluid.

Determining the evaporation rate of the spilled oil is a key element in knowing how much oil is available for recovery when the response effort begins. Estimating the evaporation rate for the blowout scenario is difficult because of the number of physical processes that are involved during the spill. Some of the oil will be evaporated as the oil is transported in the air in the blowout geyser. Some of the more volatile components will be evaporated soon after the oil is deposited on the ground, and some will be evaporated over a longer period of time at a rate that is dependent on the surface area exposed and the ambient air temperature. Since the blowout scenario occurs on the north slope in winter, low temperatures will have an important affect on suppressing the evaporation rate. Using the evaporation schedules recently developed by Mackay and Nadeau, computations show that 91% of the oil spill would be expected to remain after a period of 30 days (58). This assumes that most of the oil available for evaporation is on the pad and that the ambient air temperature is -30°C. Most observers feel that this rate of evaporation is rather low, even in view of the very low temperatures that occur in the spill area. Earlier work performed by Mackay indicates that even at low vapor pressures that accompany air temperatures of -34°C, an evaporation rate of about 35% can be expected in a period of 30 days (63). It was therefore decided to establish an evaporation schedule that would be suitable for this scenario and reflect these results.

For this scenario it is assumed that the spilled oil evaporates at a rate of 2% per day for a period of 10 days, then the evaporation stops. Although 2% per day may seem like a low rate, it amounts to about 20% in a period of 10 days not accounting for the fact that the size of the spill is changing daily for the first 20 days. Assuming that the evaporation essentially stops after 10 days is justified by observing that in nearly all cases, most evaporation takes place soon after the spill occurs and that on the north slope the oil is expected to become hard soon after it is on the ground. At spring thaw it is assumed that the oil again begins to evaporate, now at a rate of 0.3% per day and continues at this rate for a period of 60 days.

Since the oil is spilling as well as evaporating over the first 20 days of the scenario, the application of these rules is somewhat more complicated. For days 1 to 10, oil is accumulating at a rate of 5,000 barrels per day and the oil that has already spilled is evaporating at a rate of 2% per day. Thus each day 2% evaporates but 5,000 barrels is added, so that the total available for evaporation on the next day is larger. On days 10 to 20, oil continues to accumulate at a rate of 5,000 barrels per day, but on day 11, what remains of the first 5,000 barrels has stopped evaporating. For this period of time, one day's accumulation stops evaporating each day as another day's accumulation is added, so that over the entire period, 50,000 barrels evaporates at a rate of 2% per day, or 10,000 barrels is evaporated. During days 20 to 30, the first 50,000 barrels spilled has completely stopped evaporating. On the 21st day the 5,000 barrels spilled on the 11th day stops evaporating, and so forth, so that during this period 50,000 barrels is available for evaporation on the 21st day, 45,000 barrels on the 22nd day, and the amount available for evaporation is reduced by 5,000 barrels each day. Thus the amount evaporated in days 20 to 30 is the same as the amount evaporated in days 1 to 10.

To account for all of the oil that has spilled, it is necessary to point out that some of the oil sinks into the gravel pad and is not available for evaporation. The gravel on the pad is built up to a depth of about 60 cm above the permafrost. Assuming a gravel porosity of 0.3, it has been calculated that 6,700 barrels of oil will sink into the pad and not be available for evaporation.

Figure 34 shows the complete oil spill budget for the Meade River blowout. Oil spills at a rate of 5,000 barrels per day accumulating to 100,000 barrels over a period of 20 days. Of that total spill, 42,250 barrels falls into the reserve pit, 35,830 barrels falls on the pad, and 6,700 barrels is absorbed into the gravel on the pad. At the end of 20 days, 15,050 barrels has evaporated, and at the end of 30 days, 20,000 barrels has evaporated, amounting to 20% of the total that had spilled. An estimated 170 additional barrels are lost to evaporation as mist.

Figure 35 shows a plot of the oil remaining for recovery. After the first 30 days, evaporation basically stops for the remainder of the winter. At spring thaw in June, evaporation begins again, but at a much lower rate. Now evaporation is only 0.3% per day for a period of 60 days. If the amount available at the beginning of thaw is A, then the amount available at the end of thaw is $A \cdot (1 - 0.003)^{60}$ or $A \cdot 0.835$. At the end of thaw, 61,064 barrels are available on the surface and 6,700 barrels are still in the gravel. Thus, 67,764 barrels are still available for recovery.

Problems in Projection of Spill Behavior

The preceding spill behavior model must be considered only as a best estimate of what might occur in the case of a blowout in this area of the North Slope. The weakest part of the analysis occurs in the assumption of the distribution of particle size. Better information is needed concerning this distribution in order to have greater confidence in predicting the way that the oil will be distributed on the ground in the spill area. We also believe that attempting to develop a single particle size distribution for the oil/air medium is far too simplistic an approach to a much more complicated problem. We believe that there are likely to be a number of possible particle size distributions that depend on the conditions at the blowout. Operators in the field have reported observing blowout conditions in which the heaviest deposits of oil are close to the well, similar to the situation we projected for this scenario. Other observers report blowouts in which virtually no oil falls within a radius of about 150 meters of the well. That is, the heaviest deposits form an annulus around the well rather than a thick deposit at the well site. That is the inverse of the situation we describe in this scenario.

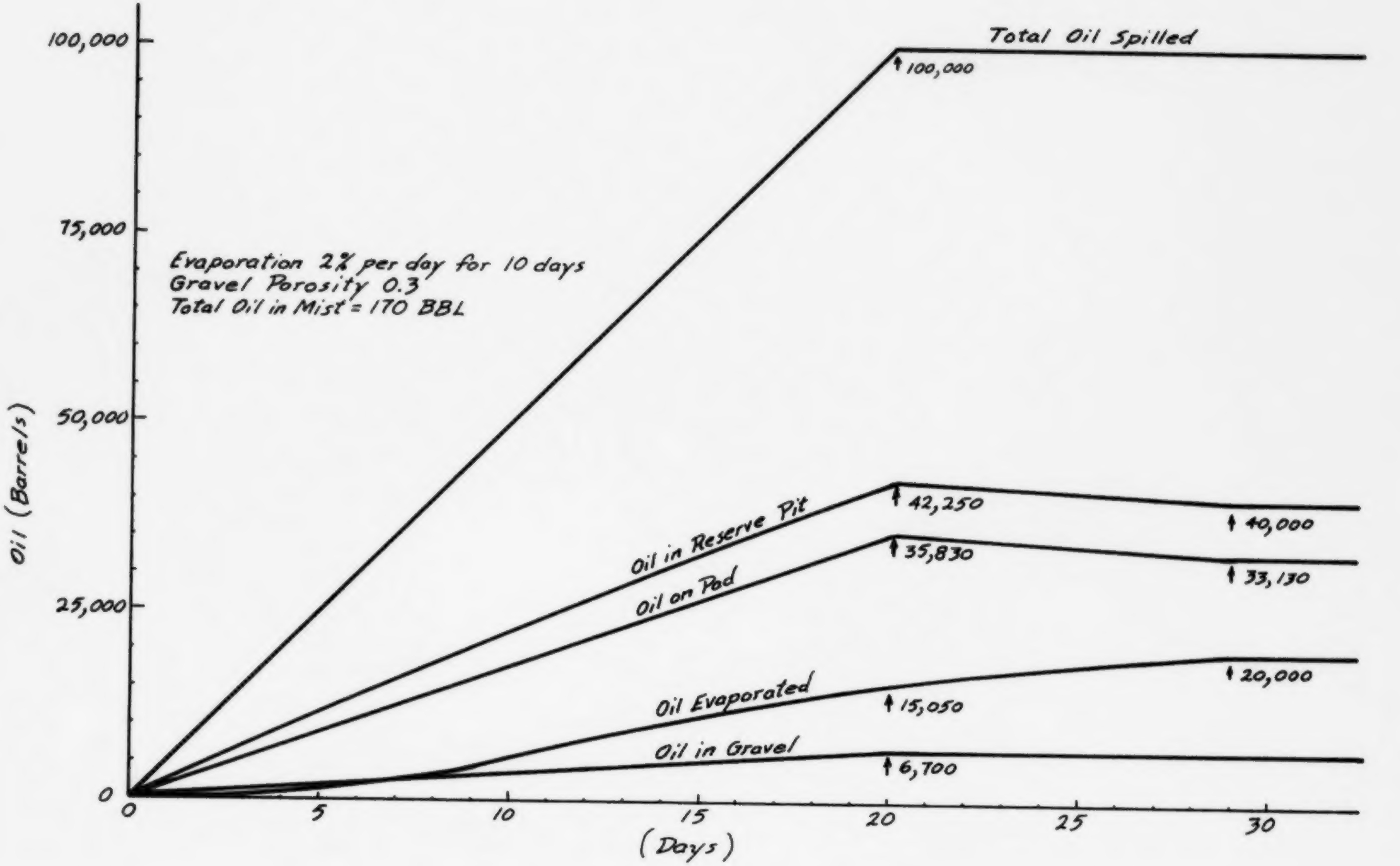
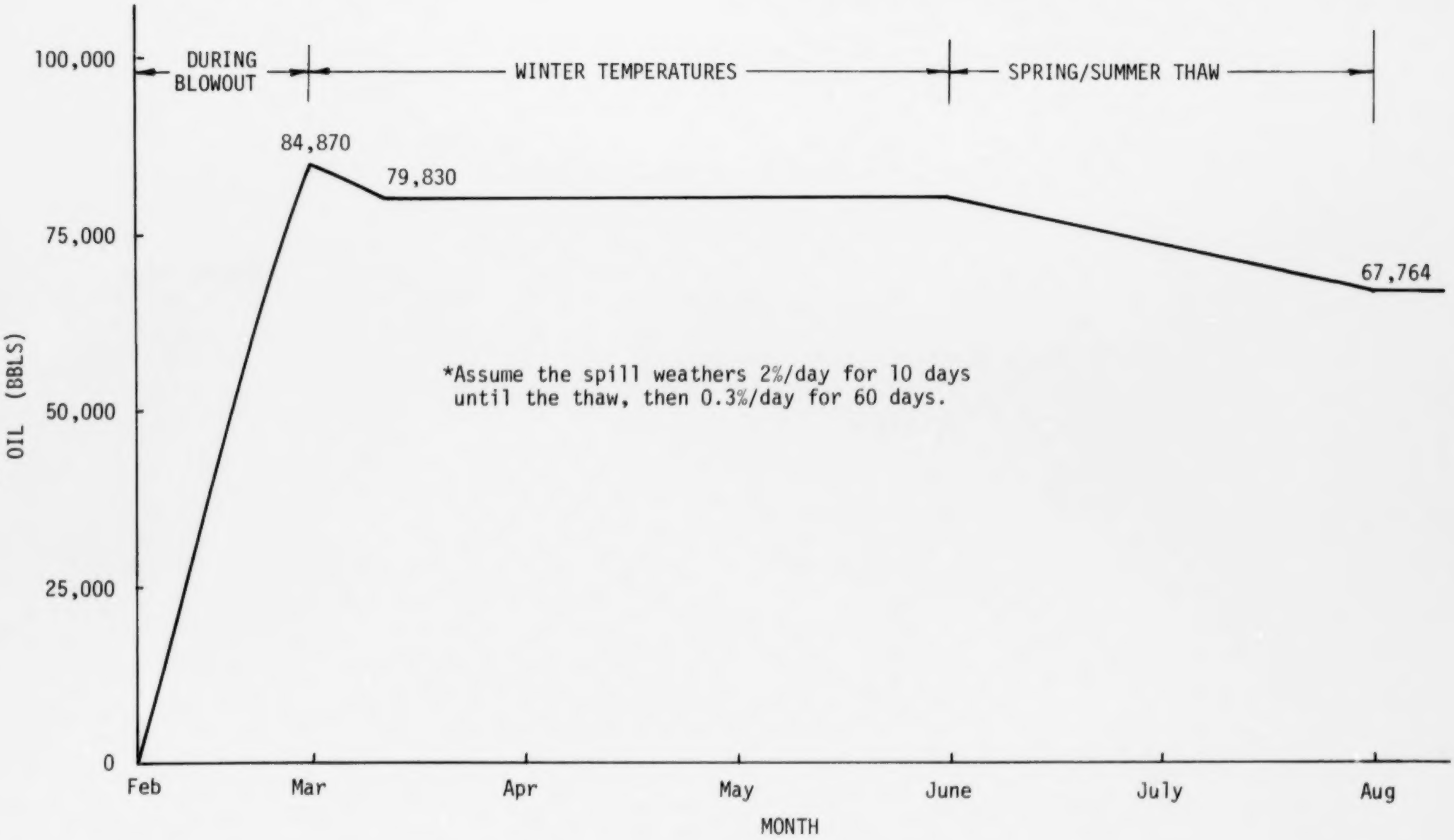


Figure 34. Oil budget, Meade River.



*Assume the spill weathers 2%/day for 10 days until the thaw, then 0.3%/day for 60 days.

Figure 35. Oil available for recovery, blowout scenario.

From these observations we conclude that there may be a number of different particle size distributions possible depending on the characteristics of the well and the local environment. We therefore recommend that additional studies be conducted for blowout conditions in air to determine the causes of the various particle size distributions and to develop the models needed to predict these outcomes.

There may also be some question about the extent to which the cooling oil will flow after it hits the ground. Operators in the area report that spilled crude becomes hard in two to three hours in the winter; however, a thick layer of oil accumulating during a blowout cannot be expected to cool as quickly, and therefore its behavior on the ground may not be exactly as predicted here. Additional research is also needed in order to better predict the behavior of the warm oil issuing from a blowout in a very cold environment.

The R&D initiatives recommended in the preceding paragraphs for predicting spill behavior will be consolidated with other R&D recommendations in a section that follows.

SCENARIO 2 - PIPELINE SPILL

The Spill

As spring breakup was beginning during the second week in May, a pipeline surveillance flight detected oil on the river ice and eastern shoreline of the middle fork of the Koyukuk River downstream from Wiseman. Subsequent overflights confirmed the original report and determined that this crude oil spill was increasing rapidly in size downstream as the spring thaw brought water over the river ice in a dynamic, almost instantaneous, river ice breakup. The Alyeska Pipeline Company reported the spill to federal and state authorities and began a gradual pipeline shutdown to prevent surges from increasing the size of the leak. A spill response team was sent to the site and responsible pipeline officials began an investigation to determine the cause of the spill.

The source of the spill was traced to pipeline milepost 225 north of Wiseman. Figure 36 shows a cross-section of the Koyukuk River with the pipeline crossing under the riverbed at this location. An initial spill assessment determined that the leak was underground on the eastern bank of the river. Here the pipeline slopes up to a point about 61 meters from the riverbank where it continues above ground. Engineering drawings indicated that the break was about 3 m below the surface. Spill estimates indicated that the pipeline had been leaking at a rate of about 500 barrels per day for a period of about a month under the ice and the spill was only detected at breakup. A hydrologist with the spill response team explained that the oil had probably spread beneath the ground surface on the water table until it encountered the frozen river bed. The spill then spread downstream in the subsoil on the eastern side of the river until the spring thaw brought water into the river bed. As the water filled the stream bed it carried the oil into the river and the spilled oil began to flow freely with the river. The river ice broke up in a matter of days and the oil was carried downstream where it coated the riverbanks to the south.

State fish and game officials determined that the oil presented a danger to life forms in the river and may cause a serious impact to native subsistence fishing downstream.

The Spill Environment

Climate--

The region along the Middle Fork of the Koyukuk River near Wiseman is in the continental climatic zone of Alaska. Temperatures in the area historically average about -5.5°C (22°F). Average air temperatures are moderate (0°C or higher) for five months of the year and cold for the remaining months. Table 16 shows that during April and May air temperature increases rapidly to summer levels. These thawing temperatures cause a rapid breakup of the river ice and melting of snow in the surrounding highlands.

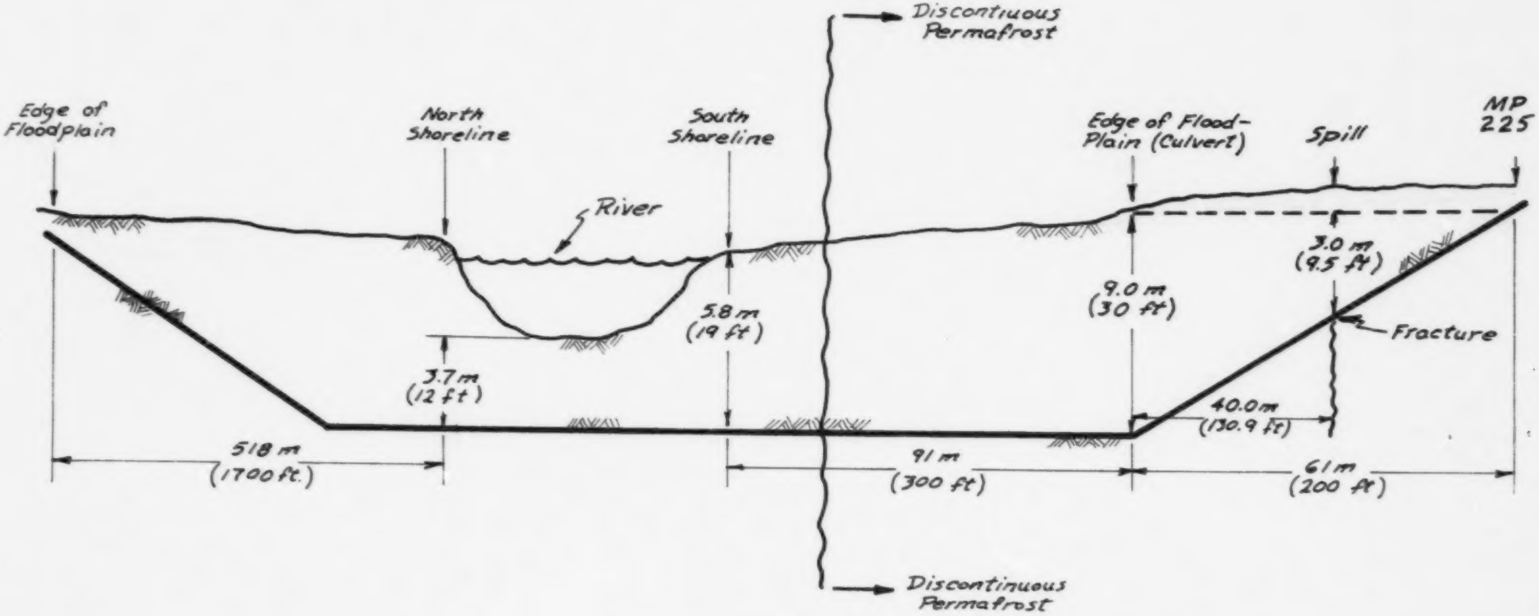

Discontinuous Permafrost
Edge of Floodplain
North Shoreline
South Shoreline
Edge of Flood-Plain (Culvert)
Spill
MP 225
River
3.0 m (9.5 ft)
9.0 m (30 ft)
5.8 m (19 ft)
Fracture
3.7 m (12 ft)
40.0 m (130.9 ft)
518 m (1700 ft.)
91 m (300 ft)
61 m (200 ft)
Discontinuous Permafrost

Figure 36. Cross-section of the Koyukuk River at the pipeline crossing near mile post 225.

TABLE 16. CLIMATIC DATA FOR THE WISEMAN CREEK

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature (°C)												
Highest	2.2	4.4	9.4	15.0	24.4	31.1	31.7	30.0	22.8	13.3	2.8	2.2
Avg. Max.	-18.9	-16.7	-9.4	1.1	11.1	19.4	20.0	16.7	9.4	-1.7	-13.9	-17.8
Avg. Min.	-28.9	-25.0	-23.9	-14.4	-2.2	5.6	7.8	4.4	-0.6	-9.4	-22.2	-27.2
Lowest	-53.9	-51.7	-50.6	-38.9	-23.3	-3.3	0.0	-7.8	-19.4	-34.4	-45.6	-50.0
Precipitation (mm)												
Mean	12.7	10.2	10.2	7.6	12.7	30.5	40.6	50.8	45.7	20.3	12.7	12.7
Maximum	50.8	38.1	33.0	22.9	35.6	63.5	86.4	137.2	127.0	88.9	40.6	43.2
Snowfall (mm)												
Mean	279.4	279.4	254.0	152.4	76.2	0.0	0.0	25.4	25.4	355.6	304.8	304.8
Maximum	812.8	1371.6	914.4	635.0	228.6	0.0	0.0	101.6	101.6	1574.8	787.4	1092.2
Average Hours of Daylight and Twilight	6.8	9.9	13.4	18.0	24.0	24.0	24.0	19.9	15.2	11.4	8.0	5.6

Meterological data taken at Bettles.

Seasonal precipitation rates in the Wiseman area are generally uniform with slightly more precipitation falling as rain in the summer months of June, July, August, and September. Snow remains on the ground until the spring thaw in May, and does not fall again until flurries begin in late August. Data taken at Bettles, about 165 km southwest of Wiseman, show that winds in this area average 6.7 kts from NNW with an extreme wind velocity of 46 kts from the southwest.

Topography--

Land Features--Wiseman is located at an elevation of 383 meters (1,286 feet) in the foothills of the Endicott Mountains in the Brooks Range. The area is drained by the Middle Fork of the Koyukuk River, as shown in Figure 37, which flows southward and empties into the Koyukuk River at Bettles. The land rises steeply on both sides of the river, from 383 m at Wiseman to heights of 1525 m (5,000 feet) and 1830 m (6,000 feet) only five miles away. The surface slope perpendicular to the riverbank in the floodplain is approximately 0.035. Above the river bed the valley floor is level for about 800 m on both sides of the river then rises in steep mountains.

Inland Waters--The Middle Fork of the Koyukuk River flows south from the Endicott Mountains in a narrow valley only 3,200 m wide. Some meandering has occurred in this valley, but the river generally flows south before turning west and joining the main stream of the Koyukuk River. The Middle Fork has a total length of 110 km (68 miles) and an overall drainage area of 2,200 square km (852 square miles). The river bed consists of coarse rock, gravel, and sediment, with the river carrying maximum sediment concentrations of 500 mg/l. Mean annual runoff in this region is less than 18 liters per km and mean peak annual runoff is 880 liters per km during the snowmelt season.

Table 17 shows detailed hydrographic data of the river at Wiseman. The time period of this scenario includes April, May, and June, when breakup occurs and water velocities reach an average peak of 3.6 knots. The stream swells to a maximum average width of 86.8 m (288 feet) in June.

The elevation of the river above sea level drops quickly through the Wiseman area. Five kilometers north of Wiseman, the river is at an elevation of 379 m (1,245 feet); at Wiseman, the river elevation is 361 m (1,185 feet); and seven kilometers south of Wiseman the river is at 335 m (1,100 feet), indicating an average southward river bed slope of about 0.004 or 4 m per km.

Ice on the Middle Fork of the Koyukuk River appears in late September, becomes a solid sheet in November, and freezes completely to the river bottom by January. Flow in the sub-river gravel begins in April and by the end of April, the ice becomes thin and ready for breakup. Runoff from area snowmelt begins to flow on top of the ice cover in early May. This water warms the ice cover which then melts, cracks, and flows downstream leaving the entire channel clear within 3 to 5 days. Ice can be expected to be strong enough to support the weight of a vehicle from October 27 to April 20 (180 days).

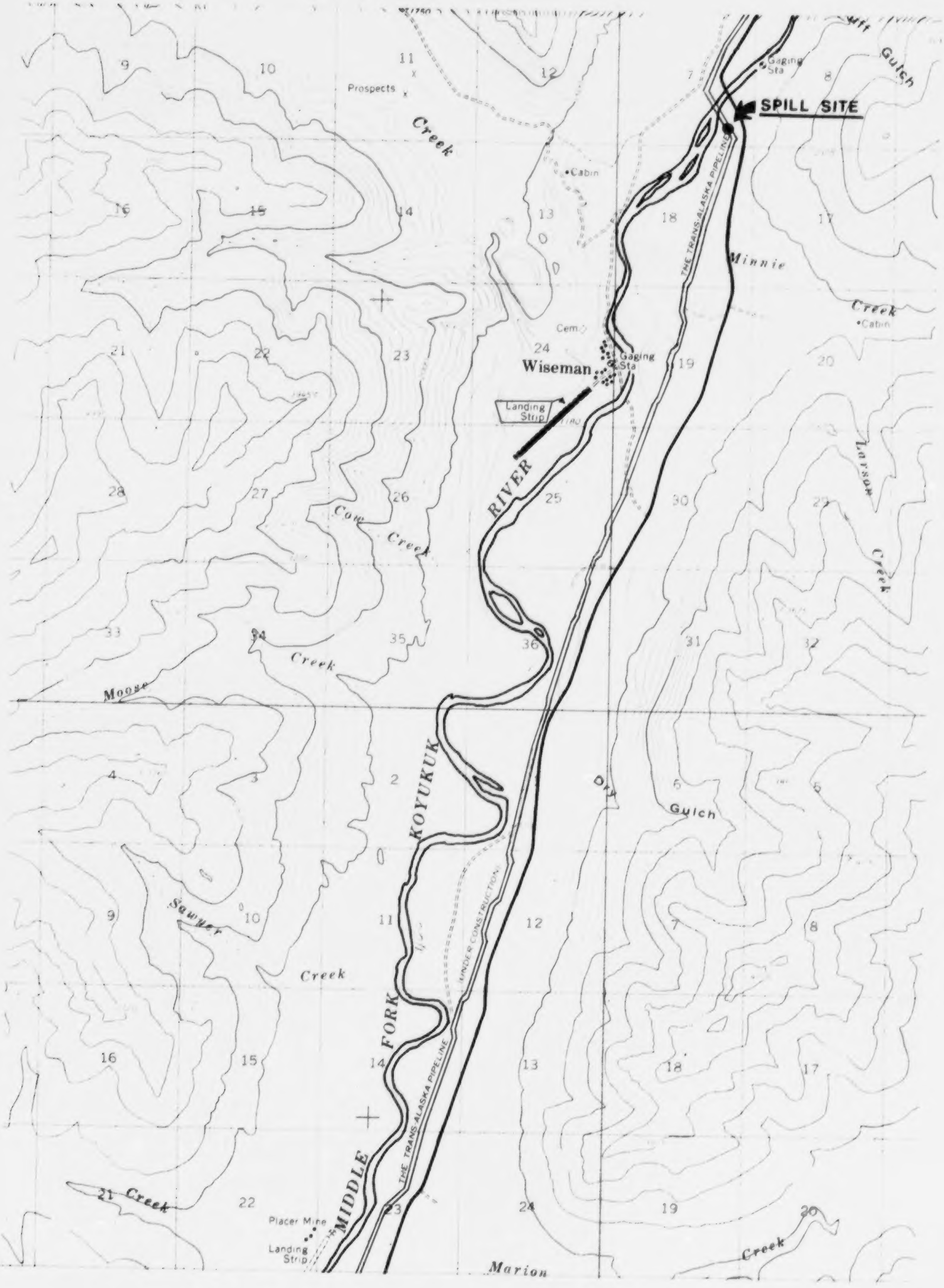

SPILL SITE
Wiseman
Landing Strip
Gaging Sta
Cabin
Cem
Prospects
Placer Mine
Landing Strip
MIDDLE FORK KOYUKUK RIVER
THE TRANS-ALASKA PIPELINE
UNDER CONSTRUCTION
Creek
Minnie Creek
Larson Creek
Cow Creek
Moose Creek
Sawyer Creek
Dry Gulch
Marion Creek
Gulch
9
10
11
12
7
8
16
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Figure 37. Map of the Wiseman area and pipeline spill site.

TABLE 17. HYDROGRAPHIC DATA FOR MIDDLE KOYUKUK RIVER NEAR WISEMAN

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Mean Width (m)	-	-	12.5	9.7	83.8	87.8	68.6	69.8	62.5	33.5	25.9	3.4
Mean Area (m^2)	-	0	0.9	1.9	75.5	104.9	39.1	41.9	37.6	14.8	8.5	0.4
Maximum Avg. Water Velocity (m/s) (kts)	-	-	0.1 0.2	0.3 0.5	1.9 3.6	1.8 3.4	1.1 2.2	1.4 2.7	1.0 2.0	0.7 1.4	0.7 1.2	0.05 0.1
Mean Velocity (m/s) (kts)	-	-	0.1 0.2	0.1 0.2	1.3 2.6	1.6 3.2	0.8 1.6	0.8 1.5	0.7 1.3	0.5 0.9	0.4 0.7	0.05 0.1
Mean Discharge (m^3/s)	-	-	0.06	0.38	115.80	171.8	35.6	38.1	27.0	5.5	2.8	0.03
Mean Water Temperature (°C)	-	-	0.0	0.9	1.6	-	15.8	11.4	5.6	0.1	0.0	0.0
Ice Condition	Solid	Solid	Cover	Cover	Break-up	Clear	Clear	Clear	Slight Shore Ice	Shore Ice and slush becoming frozen	Ice Cover	Almost Complete Ice

COMMENTS:

(1) Breakup occurs during early May over a period of 3-5 days. Water flows on top of solid ice until ice breaks up and flows downstream. At about the fifth day, the channel is clear.

(2) Freezeup generally occurs in late September and early October with shore ice forming initially followed by slush in the channel which freezes into a solid cover.

(3) River channel almost completely freezes in mid-winter.

Geology--

The river bed of the Middle Branch of the Koyukuk River is composed of gravel and large rocks carried down from the nearby Endicott Mountains. The riverbed does not generally contain permafrost. During the winter, when the river is frozen completely, some ground water flow exists in the gravel bed under the ice. Permafrost has been noted about 15 m (50 ft) from the river bank where slumping and thermokarst phenomena do occur.

The oil spill in this scenario is caused by a permafrost related ground movement. Although the design of the pipeline incorporates known possible reactions of underlying permafrost to the presence of the pipeline and related activities, permafrost is a highly unpredictable material and will cause unexpected problems for even the most carefully designed structures. It is one of these problems that causes the spill in this scenario.

Increased North Slope production resulting in increased pipeline flow rate in 1980 will increase the temperature of the fluid in the pipe. At the 1979 flow rate of 1.2 million barrels per day the oil temperature at Wiseman was 32.2°C; at the 1980 flow rate of 1.5 million barrels per day the temperature will be 35°C. This temperature rise results from the oil being in the pipeline for a shorter time, from adding energy to the fluid at pumping stations, and from increased fluid-pipe friction during flow. The temperature rise may increase the size of the thawed area around the pipe as it passes under and along the Middle Koyukuk River which may also alter the once stable condition of the permafrost along the shoreline. This scenario suggests that local permafrost instability finally damages the pipeline.

Ecology--

Wiseman is located in an upland spruce-hardwood forest that follows the Middle Koyukuk River to the south. This forest is about 5 km wide on each side of the river and is bordered by steep areas of alpine tundra. The forest area consists of white spruce, black spruce, paper birch, quaking aspen, and balsam poplar trees. Shrubs in this area include willows, alders, rodes, cranberry, currants, labrador tea, raspberry and ligonberry. Many ferns, horsetails, bluejoint grasses, and mosses thrive along the river.

Very gravelly and stony loams cover the entire area around Wiseman and to the south. Solifluction, downslope movement of thawed soil over frozen subsoil, is common in this area. The land is nonarable, but it is used by caribou and reindeer for grazing at lower elevations.

Table 18 lists the animals and birds that frequent upland spruce-hardwood forest near Wiseman. Note that the peregrine falcon, an endangered species, nest in the region. The area is also generally a suitable habitat for red squirrel, ruby crowned kinglet, and pine marten. Wandering animals such as wolf, wolverine, and raven, frequent the area. Seasonally, moose, caribou, and passerine birds may be found in the area.

Aquatic life ranges from microscopic sizes to very large fish in the Middle Koyukuk River. Zooplankton live in small numbers and include copepods,

TABLE 18. ANIMALS AND BIRDS IN THE WISEMAN AREA

MAMMALS

Masked shrew
Dusky shrew
Little brown bat
Showshoe hare
Red squirrel
Northern flying squirrel
Red-backed vole
Yellow-cheeked vole
Meadow jumping mouse
Porcupine
Coyote
Gray wolf
Red fox
Black bear
Grizzly bear
Pine marten
Ermine
Least weasel
Wolverine
Lynx
Moose
Caribou
Bison

BIRDS

Common goldeneye
Barrow's goldeneye
Bufflehead
Harlequin duck
Goshawk
Sharpshinned hawk
Rough-legged hawk
Osprey
Peregrine falcon
Spruce grouse
Willow ptarmigan
Great horned owl
Hawk-owl
Yellow-shafted flicker
Hairy woodpecker
Northern three-toed woodpecker
Barn swallow
Cliff swallow
Tree swallow
Bank swallow
Gray jay
Common raven
Black-capped chickadee
Boreal chickadee
Gray-headed chickadee
Robin
Varied thrush
Hermit thrush
Swainson's thrush
Gray-cheeked thrush
Mountain bluebird
Ruby-crowned kinglet
Northern shrike
Myrtle warbler
Blackpoll warbler
Northern waterthrush
Pine grosbeak
Hoary redpoll
Common redpoll
White-winged crossbill
Slate-colored junco
White-crowned sparrow

cladocera and ostracods. Common benthic macroinvertebrates include midges, stoneflies, caddisflies, mayflies, blackflies and freshwater mites. Some clams, snails, aquatic earthworms and flat-worms may be found in the river.

The Middle Fork is a spawning place for inconnu, king salmon and chum salmon, which are known for their lengthy swims to the spawning grounds. Northern pike, arctic grayling, helpmejack, iniakuk, lake trout and lake chub also live in the river.

Population and Society

The Wiseman/Middle Fork Koyukuk region is virtually unpopulated except for isolated mining camps and trappers. The community of Wiseman consists only of a few buildings, a landing strip, and a climate and river gauging station. Information on permanent residents is not available. Larger communities exist farther downstream, where the Middle Fork empties into the Koyukuk River. Bettles, Evansville, and Allakaket are more permanent camps and would likely be impacted by a serious river spill at Wiseman. The people in these camps are generally not permanent residents and therefore population data are not available. The camps use the river as a source of water and subsistence fishing.

Economy

Mammals and fish are important to subsistence living along the Middle Fork of the Koyukuk River. Caribou herds from the Arctic graze along the river and are taken by the people for food and skins. Fur bearing animals such as beaver, red fox, marten, lynx, land otter, mink, muskrat, and squirrel are used for clothing and crafts.

Fish such as salmon, trout and chub, are caught for food and for trimming clothing. This activity would be directly affected by a river spill. Recreation fishing further downstream will also be impacted by a spill. Commercial activity in the area is limited to trapping and selling fur-bearing animals.

Transportation

Wiseman can be reached via the TAPS Haul Road or the airstrip to the southwest of town. The Haul Road runs essentially parallel to the pipeline and is on the eastern side of the Middle Koyukuk River as the pipeline passes Wiseman and proceeds south.

The airfield at Wiseman has a gravel runway approximately 914 m (3000 ft) long and 30.5 m (400 feet) wide. The field is unattended and maintained for use by transient military aircraft. The first 90 m (300 feet) of runway is unusable (20). Ceiling and visibility conditions do not often affect aircraft operations at Wiseman; however icing conditions, runway conditions, winds and snow will be factors in determining the use of the runway.

Figure 37 shows the location of airfield, roadway and the trans-Alaska pipeline system near Wiseman. The spill site for this scenario is also noted.

Petroleum Development

The trans-Alaska Pipeline System is essentially the only petroleum related development in the Wiseman area. Information about oil storage and use in the camp is not available, but some gas and oil may be available for stranded vehicles on the haul road and for use by the gaging station personnel who are there only a few days each year. Fuel for aircraft is not available.

Spill Behavior

The behavior of the spilled crude oil in this scenario takes place in three phases:

1. Intragravel flow before the stream bed thaws,
2. Leaching into the stream bed during the various stages of breakup,
3. Open water migration downstream after breakup.

The spill site is located along the trans-Alaska Pipeline 2.5 kilometers north of Wiseman on the eastern side of the Middle Fork of the Koyukuk River. Here the pipeline is rising to ground level after passing under the river. Figure 36 shows a cross-section of the river at the spill location. The river bed itself is not frozen, but permafrost does exist along the shoreline at distances greater than 16 meters from the river bed. In these areas, ground movement can occur and it is here that a pipeline rupture is projected for this scenario. At the point of rupture, the pipe is about 3 meters beneath the ground surface in frozen, permeable gravel soil. The spill of 80,000 liters per day (500 barrels) occurs in early April, about 30 days before being detected at breakup.

The first phase of oil spill migration is the movement of oil through the subsurface gravel soil. The gravel rock is frozen together in the spill area but voids exist that allow the oil to move. The oil is assumed to accumulate on the water table and spread on the water table surface. The increase in spreading area on the water table, first assuming a static spill situation, is calculated by

$$S = \frac{1000}{H} \left(V - \frac{A \cdot d}{K}\right)$$

where, for this particular spill,

V = spill rate (m^3/day)
S = maximum spread area (m^2)
A = area of infiltration (m^2)
H = thickness of the oil layer in the capillary zone (mm)
d = depth to groundwater (m)
K = permeability constant.

Noting that for large spills the $A \cdot d/K$ term becomes negligible in comparison to the other term, and using H = 5 mm and V = 500 BBL/day = 79.5 m^3/day, the spread area increase each day is:

$$S = \frac{1000}{5 \text{ mm}} \ (79.5 \text{ m}^3/\text{day}) = 15{,}900 \text{ m}^2/\text{day}.$$

The resulting slick, if occurring on a static level water table, would take a circular form of diameter $2\sqrt{S/\pi}$ and thickness H = 5 mm.

Actually, the spill is not spreading on a static groundwater table but is instead spilling into a uniformly flowing groundwater table. The flowing groundwater will tend to deform the slick, bending it in the downstream direction. Since oil and water are immiscible, the shape that the slick assumes is a streamlined shape analogous to a stagnation curve generated by a point source issuing into a uniform flow. This shape is shown in the insert in Figure 38. Note that the spill does extend upstream of the source. As the spill continues, the upstream portion of the spill remains identical but the slick elongates in the downstream direction, always assuming the streamline shape. From continuity arguments, the increased oil spilled each day will show up as an equal added area at the downstream end of the slick. Once the total nondimensional spill area, defined below, has reached a value of 60, the streamlined boundary of the slick has become roughly parallel and any further spillage will add simple extensions of rectangular area to the end of the slick.

To use Figure 38, the static spill area is computed as given earlier. The groundwater flow is computed according to Darcy's equation:

$$U_\infty = \frac{k_o}{\mu} \ \frac{dh}{dx}$$

where k_o is the physical permeability of the soil medium, μ is the viscosity of the groundwater, and dh/dx is the slope of the groundwater table. For this scenario, a groundwater flow velocity of 0.23 cm/sec was used. A nondimensional spill area defined as:

$$\text{Spill Area} \cdot \left(\frac{2U_\infty H}{V} \right)^2$$

is then computed and used to enter the vertical axis. The plotted curve of Figure 38 then gives the corresponding slick length. For each slick area a slick length in meters can be determined by dividing the appropriate point on the abscissa by

$$\frac{2 \ U_\infty H}{V} \ .$$

The frozen water of the stream before breakup prevents the spill from developing into the perfect shape shown in Figure 38. The barrier of ice distorts the shape of the spill into the area represented by Figure 39 based

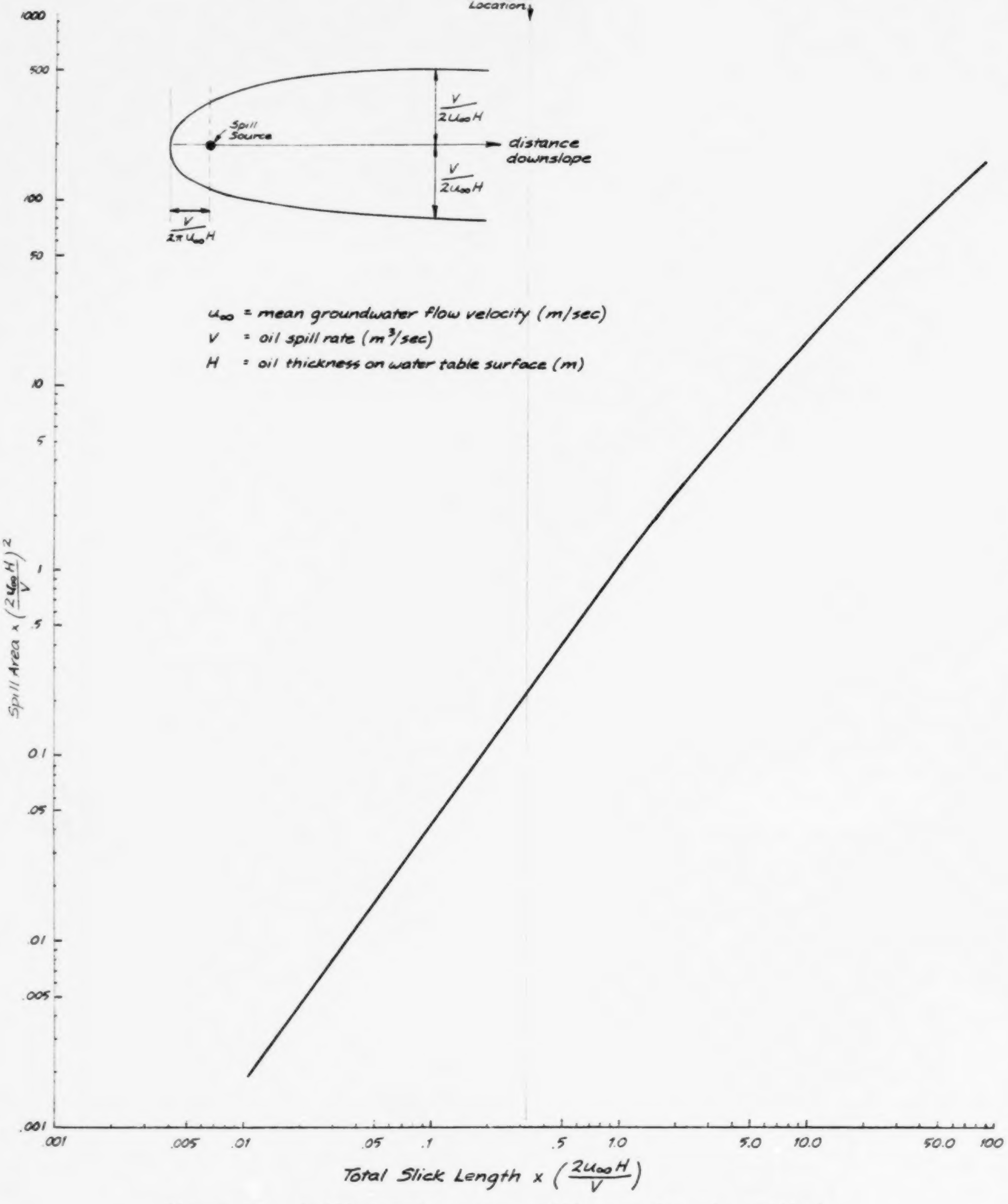


Figure 38. Spill length versus spill area for oil spilled in a sloping soil medium.

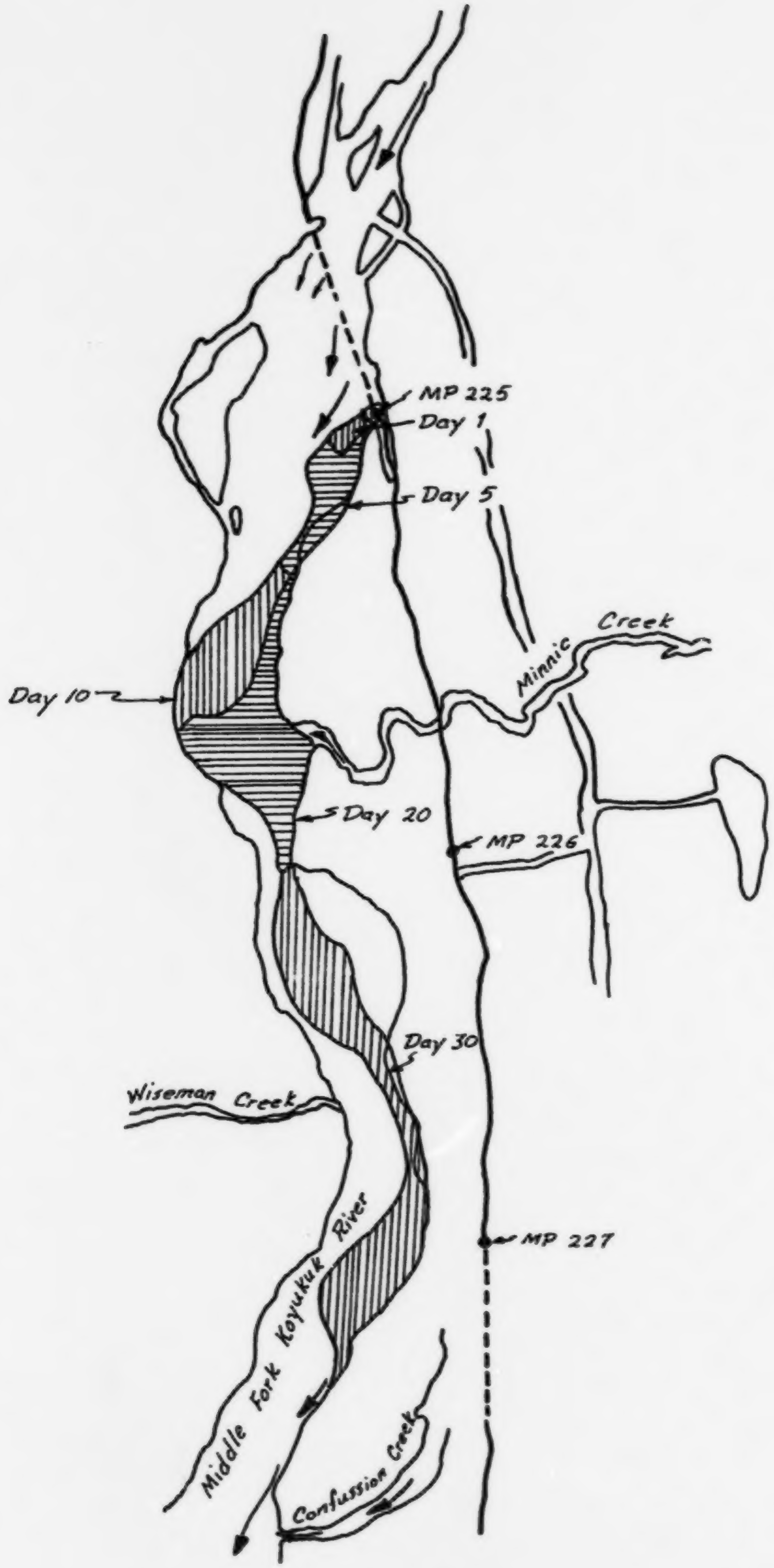

MP 225
Day 1
Day 5
Day 10
Day 20
Day 30
MP 226
MP 227
Minnic Creek
Wiseman Creek
Middle Fork Koyukuk River
Confussion Creek

Figure 39. Detailed view of the pipeline spill before breakup.

on the groundwater velocity of 0.2 cm/sec. The thickness of the oil layer is assumed to remain at 5 mm based on the values given in Table 10. The oil moves on the groundwater table along the frozen river, constrained to the eastern bank. U.S. Geological Survey records show that as the air temperature rises in the area and runoff increases from snow-melt, the river begins to flow both above and below the thick ice cover. The ice cover melts quickly and within 2 to 3 days starts to crack and flow. The runoff toward the streambed forces any subsurface oil to leach into the flowing stream water and begin its movement downstream. As runoff rates increase daily and oil is carried into the stream at higher rates, the oil becomes visible to pipeline surveillance flights. Pipeline shutdown now limits the spill to a finite amount of oil, but the size of the spill in the river increases as oil originally spilled along the downstream bed is carried into the flood stage Middle Koyukuk currents.

The third phase of spill movement occurs on open water. As the Wiseman area clears of ice, the oil still leaching into the stream moves down the river at approximately one-half the mean current speed of the water. About one-half of the total oil spilled will remain in the ground and along the shoreline in the original spill area, and 8% of the oil spilled will have evaporated while in the ground, leaving a total of 42%, or 1,002 m^3 (6,300 BBL), of the oil to move downstream (64). Based on literature summarizing oil spill effects on gravel shorelines, this crude oil will coat the shoreline to an average thickness of 3.0 mm (65). The sudden rise and recession of river levels during breakup, and the subsequent coating of the shoreline as a result of the water level drop, is analogous to oil accumulation on coastlines during ebb tide. The width of the oil-coated shorelines is the distance the river width recedes between breakup and normal summer flow. In this scenario, oil coats the shoreline out to about 10 m on both sides of the river. It should be noted that some areas will have more oil than 3 mm, while others may not be oiled at all. The oil coated shoreline is expected to have a range of thickness of 1 to 5 mm and a range of coverage of 50 to 100 percent.

Table 19 summarizes the fate of the spilled oil and shows that the length of oiled shoreline downstream from the original spill area extends about 16.7 km (10.4 miles). A small amount of oil will travel farther downstream, but this transport is assumed negligible in comparison to the large area of impacted shoreline. The spilled oil will cover the impacted areas of the shoreline after about two days, assuming that the leaching of oil from the subsoil into the river is a gradual process. After the oil has coated the shoreline, weathering will continue until about 30% of the oil coating the shoreline has evaporated. This will occur in about eleven days, then evaporation will essentially stop (58). The oil remaining in the river bank at the original site will continue to leach out into the river. This oil will constitute a continuing spill in the river and will be less likely to coat the river bank after the original spring flood has subsided.

In summary, oil accumulates in the subsoil before breakup, as shown in Figure 39, in the area directly downstream from the pipeline rupture. After breakup, oil is carried farther downstream and coats the shoreline more than

TABLE 19. FATE OF SPILLED CRUDE IN PIPELINE SPILL SCENARIO

Total Oil Spilled, 30 Days @ 79.5 m^3/Day	2,385 m^3
Total Oil Evaporated After Breakup (8% of Total)	- 191 m^3
Total Oil Remaining at Original Spill Site (50%)	-1,193 m^3
Oil Traveling Downstream (42%)	1,002 m^3
Width of Shoreline Impacted	20 m
Average Thickness of Oil Onshore	3.0 m = 0.003 m
Length of Shoreline Impacted	16.7 km (10.4 mi)

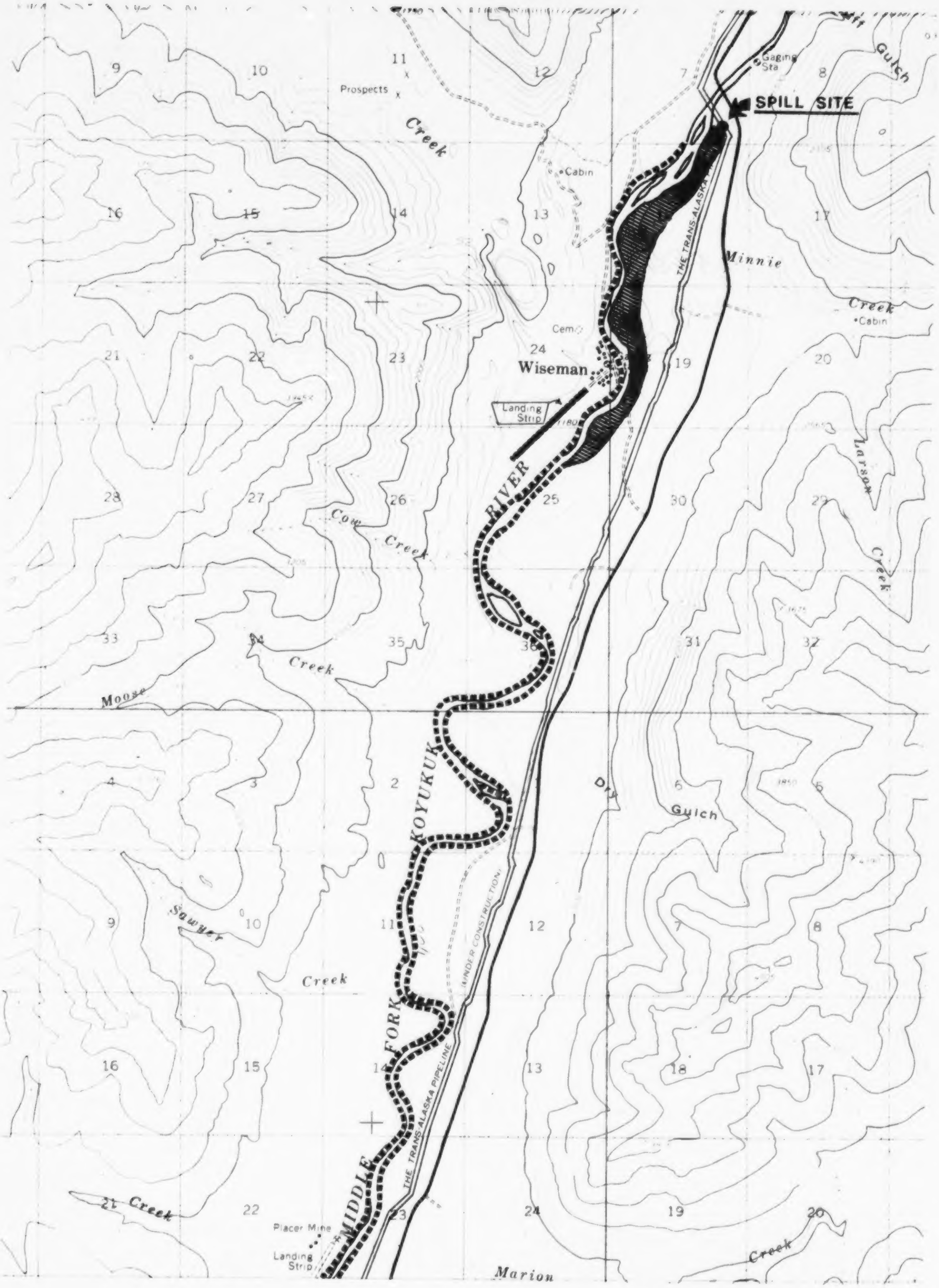
16 km downstream as shown in Figure 40. Oil in the river bank at the original spill site will continue to leach out causing a continuing spill in the river.

The pipeline spill behavior model assumes that the oil leaks out of the pipeline at a relatively low pressure. Although a similar underground leak has already occurred, some observers believe the oil is more likely to exit the pipe under high pressure creating a blow-hole through the ground and the ice so that the spill would be immediately visible. Some observers also believe that the spilled oil would find its way up through cracks in the frozen river bed and become visible. This, of course, is possible, but many Alaskans report that solidly frozen streams generally have a gap between the ice and the stream bed providing an ample volume for the flow of spilled oil. Further, there seems to be evidence indicating that the oil could indeed flow in the apparently dry stream bed over the water table. Finally, some observers feel the spilled oil would quickly melt the mantle of ice and become visible. This, of course, would depend on the temperature, amount, and distribution of the spilled oil.

Problems in Projection of Spill Behavior

The spill as it is described in this sceanrio is a conservative projection of what may happen, perhaps what could be called a worst case for the pipeline crossing under a river. We believe our description of the spill behavior, based on a methodical engineering analysis, is the best that can be presently offered using available theory and experience. Spill behavior prediction could be improved with more detailed information on how crude oil will spread in the gravel/sand layer in the apparently dry riverbed. More information is needed concerning the holding capacity of various types of river soils. This holding capacity, and the movement of a spilled product in these soils, must also be known in terms of oil type, viscosity, and temperature. A more detailed understanding of the rate of heat exchange in these environments is also required. It is necessary to know more precisely if the spilled oil will melt frozen soils and the extent to which the warm oil may melt an ice cover.

Improving existing spill behavior modeling efforts in these conditions presents a rather urgent requirement. A pipeline break at or near a river crossing presents one of the most serious spill situations that can be postulated. Alaskan streams are highly sensitive to the impact of spilled oil. In addition, the oil spilled into a swift stream is difficult, if not impossible, to control. In our scenario the pipeline break was located in a bank adjacent to the stream. This is probably the point of the stream crossing where the pipeline is most vulnerable. Although the pipeline may be less likely to break where it passes directly under the stream bed, a break there, if it did occur, would result in a more severe environmental impact. Once break up occurred, the oil is likely to be gone with almost no chance of retrieval. Knowledge of spill behavior, and the related actions needed to minimize spill impact, require that an additional effort be made to understand the problems of spill behavior and spill response at river crossings.


SPILL SITE
Gaging Sta
Prospects
Cabin
Cem
Wiseman
Landing Strip
Creek
Cow Creek
Moose Creek
Sawyer Creek
Minnie Creek
Larson Creek
Dry Gulch
Gulch
MIDDLE FORK KOYUKUK RIVER
THE TRANS-ALASKA PIPELINE
UNDER CONSTRUCTION
Placer Mine
Landing Strip
Marion Creek
Creek
9
10
11
12
7
8
16
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13
17
21
22
23
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19
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Figure 40. Oiled areas after oil migration, pipeline spill.

Recommended R&D initiatives intended to improve our capability to predict oil spill behavior will be included along with other R&D recommendations in a section that follows.

SCENARIO 3 - AIRPORT FUEL FARM SPILL

The Spill

Early in June a sheen of oil was noticed on the Kuskokwim River adjacent to the city of McGrath. The source of the spill was not known and did not appear to be associated with city fueling operations since a barge had not called at the city for a period of several weeks. In addition, there had been no reported spills from tank trucks or from surface fuel transfer lines. The operations manager of the city fuel distributor identified the product as predominately jet fuel with a smaller percentage of stove oil and aviation gasoline mixed in. A preliminary investigation showed that the riverbank east of the fuel farm was oiled and the product appeared to be leaking into the river at this point. The spill was reported to federal and state authorities and assistance was requested from the Alaska Department of Environmental Conservation (ADEC) Region II Office in Anchorage.

A short time after the news of the spill was known around the city, residents in the area to the west of the fuel farm reported that their well water smelled and tasted of oil. Health officials inspected these and other wells in the area and found them to be heavily contaminated with a petroleum product. Wells for eight residences close to the fuel farm were declared to be unfit for use because of health reasons and were closed. Residents two blocks beyond this area also noticed the odor of oil in their water. These wells were not found to be unfit for use, but residents began going to more distant neighbors to get water for drinking and cooking.

When the state oil spill specialist arrived from Anchorage on the day after the initial report, oil was leaking from the bank of the river at a rate of about 50 liters per hour or 1200 liters per day (~317 gallons). The product was also continuing to contaminate the water supplies of the residences that had been inspected. The spill specialist assessed the impact of the spill and determined that the greatest immediate danger was to the health of the people in the affected houses and the next danger was the possible impact the spilled oil would have in the Kuskokwim River. He therefore began planning his response effort with first priority given to correcting the problem in residential water supplies. At the same time he directed personnel at the fuel farm, which was the apparent source of the spill, to determine the source of the spill and stop the flow. A preliminary investigation of the extent of the spill determined that about 111.3 m^3 (30,000 gallons) had spilled. The product appeared to be a mixture of jet fuel and aviation gasoline.

The Spill Environment

Climate--

McGrath is in the Transitional Climate area of Alaska with characteristic cold, dry winters and warm, wet summers (66). The mean annual temperature is -3.6°C (25.5°F) and the frost free period is generally about 120 days. Average summer temperatures are in the mid-teens in degrees C (lower 60's °F), and average winter temperatures are below -22°C (-8°F). The transition between summer temperatures and winter temperatures is generally short. Although winter temperatures may drop to -46°C (-50°F) and remain that low for a period of 5 to 10 days, warm maritime air may also cause winter temperatures to rise to 7°C (45°F) and remain at that level for one or two days (67).

The mean annual precipitation is 48.6 cm with more than half of this amount falling from June through September. The area can be classified as very moist. The strongest winds come from the south in all months. Prevailing winds are from the south in the summer and from north or northwest in other seasons. The average cloudiness on an annual basis is seven-tenths. Table 20 shows average climatic conditions for each month of the year at McGrath (2,67).

Topography--

Land Features--The Upper Kuskokwim region has rugged mountains, hilly uplands, gently sloping piedmont areas, and generally flat lowland areas (67). The elevations are about 101 meters (300 feet) in the lowlands to 1830 meters (6,000 feet) in the mountains of Alaska Range. The city of McGrath is at about 102 meters above mean sea level. The region is drained by the Kuskokwim River and its tributaries. McGrath is located on the Kuskokwim River at the junction of the Takotna River as shown in Figure 41. The topography at McGrath is that of a broad flat floodplain with an overall relief that does not exceed 3 meters. The Kuskokwim River, a broad, meandering river, is the dominant feature of the area. Additional information on the character of the river and adjacent area is provided in the sections that follow.

Inland Waters--The Kuskokwim River meanders across a broad floodplain eroding cut banks on the outside curve (fast side) of the river and depositing sediments on broad surfaces on the inside (slow side) of the curve. The sediment deposition forms broad, alluvial fans with distinct lines of vegetation parallel to the curvature of the river. The roots of these fans are then gradually undercut to form ox-bow lakes.

The floodplain of the Kuskokwim River is 5 to 8 km wide and is bordered by bedrock uplands and high terraced sand deposits (67). The Takotna River, which meets the Kuskokwim at McGrath, has a sinuous meander pattern in a 1.6 to 2.4 km floodplain and is also bordered by bedrock uplands. The banks of the Kuskokwim along the meander plains are alternately gentle slopes and steep cut banks. The banks are 1.5 to 2.4 meters high above the mean summer flow of the Kuskokwim near McGrath and are progressively higher downstream. The overall topography of the area is flat, but it is also highly irregular because of meander scrolls and scars that contain many ox-bow lakes at various stages of filling.

Because of the constantly changing riverbed at McGrath, local soils or sediments in the area are referred to by residents as "old riverbed"; sand, silt, organic material, and some gravel locally. In some places the sediments are a compact, sticky silt which represents the fill of ox-bow lakes. Older parts of the meander plains are covered with peat and bog deposits. The amount of gravel in the deposits varies locally. The floodplain of the

TABLE 20. ENVIRONMENTAL DATA FOR McGRATH (2,67)

MONTHLY AVERAGES	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Temperature (°C)	-22	-18	-14	-4	+6	+12	+14	+11	+6	-4	-14	-22
Precipitation (cm)	2.8	2.8	2.5	.8	2.3	5.1	5.6	8.6	5.6	3.8	2.5	3.0
Freezing rain/ drizzle (% frequency)	.9	.4	.1	.1	0	0	0	0	0	.5	.7	.4
Rain/drizzle (% frequency)	.8	.1	1.7	2.9	9.6	15.0	18.9	25.0	18.5	5.7	1.1	.4
Snowfall (cm)	33	31	31	13	3	-	-	-	-	20	31	46
Snow (% frequency)	20.1	22.8	17.0	14.0	2.6	0	0	0	2.4	16.9	25.7	24.9
Blowing Snow (% frequency)	.1	.2	.1	0	0	0	0	0	0	0	.1	.2
Sky cover (mean tenths)	5.7	6.1	5.6	6.4	7.1	7.8	8.0	8.4	7.7	7.5	6.9	6.2
Fog (% frequency)	11.1	6.8	4.6	4.7	1.7	2.3	3.6	7.2	4.1	6.5	7.0	13.2
Wind Direction Velocity (kts)	NW 2.3	NW 3.0	NW 3.5	N 4.3	S 4.6	S 5.2	S 4.6	S 4.5	N 4.1	N 3.2	N 2.3	NW 2.3
Hours of Daylight	5.7	8.8	11.7	14.7	18.4	20.3	19.3	16.3	13.2	10.3	6.8	4.7

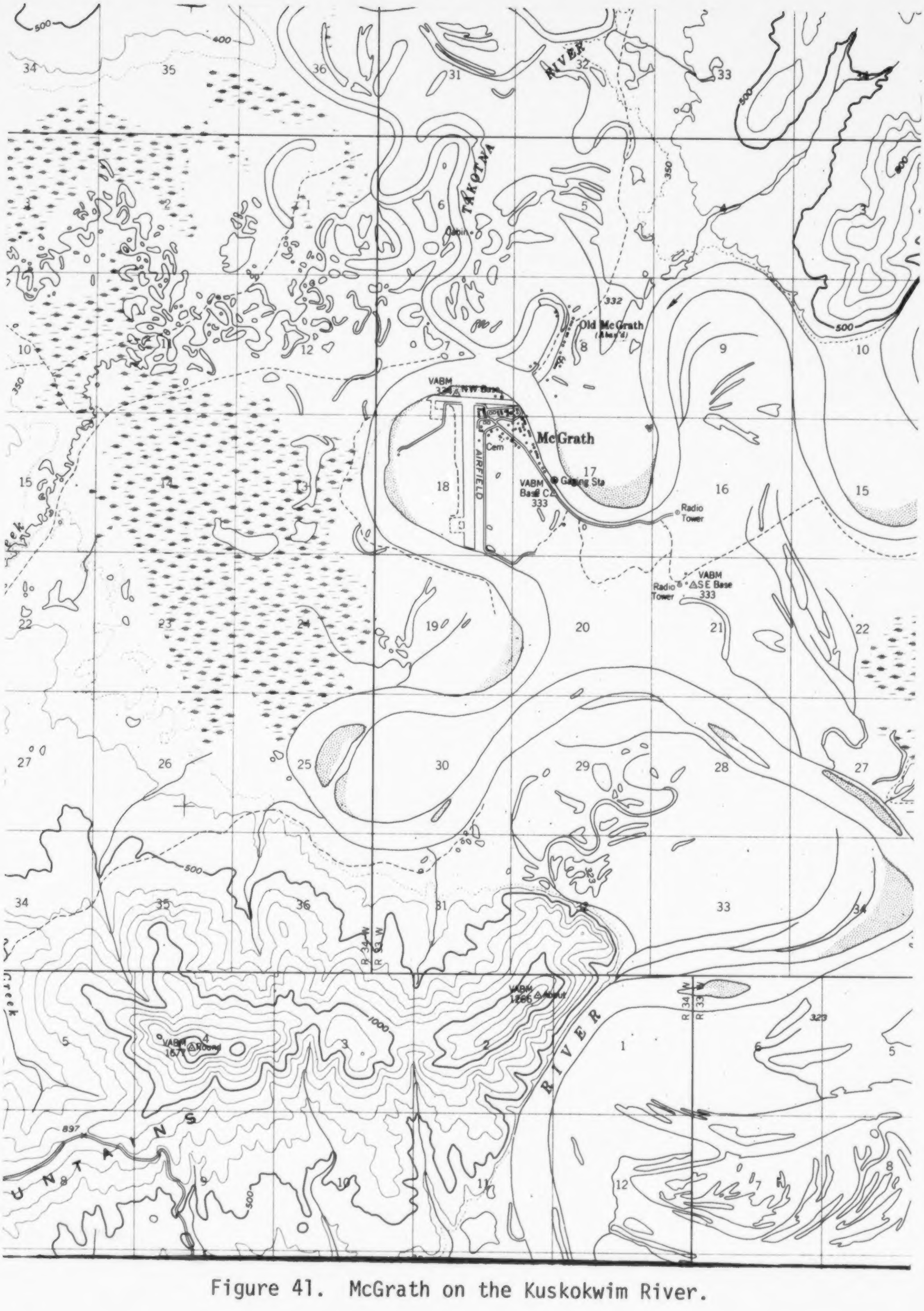
TAKOTNA
RIVER
Old McGrath (Aban'd)
McGrath
AIRFIELD
Cem
VABM NW Base
VABM Base C 333
Gaging Sta
Radio Tower
VABM SE Base 333
Radio Tower
VABM 1266 About
VABM 1677 Round
RIVER
R 34 W
R 33 W
500
400
350
332
1000
897
323

Figure 41. McGrath on the Kuskokwim River.

Takotna River has fairly extensive gravel deposits that are exposed in cut banks where the gravel can be seen to be overlain with finer grain material. The Kuskokwim River is about 430 m (1,400 feet) wide at McGrath and about 9 m deep in the deepest part. The normal river flow rate in the vicinity of McGrath during June is about 1.4 knots.

Flooding of the Kuskokwim River at McGrath usually occurs in mid-May during breakup when ice may ground or jam in bends in the river causing an immediate backup of the heavy spring flow. In fall, flooding may result from the heavy rains that occur in August and September. Although rainfall floods occur less frequently than ice jam floods, they may be more destructive because they have a higher velocity of flow and persist for longer periods of time. Ice jam floods will crest rapidly and descent rapidly when the ice jam breaks. The velocity of water in the flooded areas depends on the location of the jam; an ice jam downstream will result in a low velocity flood and a jam at or near the city will result in essentially a still water condition. Rainfall floods, on the other hand, crest more slowly, have much higher currents (and therefore are more destructive), and recede more slowly. Table 21 shows the expected characteristics of the 100 year and 500 year flood events along with a recent flood event.

TABLE 21 FLOOD EVENTS ON THE KUSKOKWIM RIVER AT McGRATH

Flood	Elevations (m above MSL)	Flow (m^3/s)	Average Velocity Mean Channel Flow (kts)
500-Year	103.5	4049	3.0
100-Year	102.9	3115	2.7
Potential Ice Jam	103.3		
May 1972 Ice Jam	103.0		

The danger of flooding at McGrath can be appreciated when one realizes that there is no high ground in the city, and typical elevations are in the range of 101.8 to 103.0 meters above mean sea level.

Freezeup on the Kuskokwim River near McGrath occurs about the first of November. In an average year the ice will be thick enough to support the weight of a man by 10 November and will remain that strong for a period of 184 days (2). The ice can be expected to be strong enough to support the weight of a vehicle by about 23 November and will remain that strong for a period of 170 days. Breakup occurs on about 11 May. The ice is strong enough to support the weight of a vehicle until breakup and within a day or two it is no longer strong enough to support the weight of a man.

Many lakes occur in the Kuskokwim drainage area. These lakes are not far above the meander plains that border the river and are locally interspersed with bogs (67). The lakes are generally small with the largest being aboug 3 km long and 1.5 km wide. Many lakes have floating mats of vegetation extending out from the shoreline. The surfaces that are marked by many lakes are different from the bogs in that they have no streams and are not drained. The lakes are often enlarged by thawing of permafrost along the lake shore.

Bog flats are the wetland form of the area. These flats may cover between 1/4 and 3/4 of the entire area of the meander plains (67). The bogs have an irregular shape and are often connected between areas of firmer ground. The firm ground areas have black-spruce muskeg vegetation and have permafrost 0.5 to 1.0 meters below. Permafrost is not encountered at 2 meters in the bog areas although it may be present deeper. Bogs tend to extend themselves by thawing the permafrost under the stable ground along their edge. As the banks thaw, they slump leaving depressions that fill with water and bog vegetation begins to establish itself in the exposed area.

Geology--

Permafrost is present in the lowland region of the Kuskokwim River. The permafrost is generally evenly distributed where it occurs and is not marked by ice lenses or wedges. In areas where black spruce and sphagnum moss grow, permafrost is only 0.5 m to 1.0 m below the surface (67). Where the moss is less than 30 cm thick, the permafrost is at much greater depths or may be entirely lacking.

Wells at McGrath give a good indication of the depth of the permafrost. On older parts of the meander scrolls, the permafrost layer is higher. Wells in these areas are reported to be 4.5 to 12 m deep. On a new meander scroll, the FAA facility at the airport has a well that is 74 m deep and is ice free. Residents report that most wells are at a shallow water table that is about 7.6 m deep. They also note that there may be some frozen areas between that level and the ground water. Ground temperatures in the range of depths where wells are generally located, that is from about 4 m to 7 m, range from about 1°C to 5°C (2). The shallower depths have colder temperatures in winter and warmer temperatures in summer, while the deeper wells, about 7 m, stay close to about 3°C all year. The presence of permafrost is significant in considering the fate of inland oil spills in that permafrost prevents the filtering of water downward with a resultant increase in surface runoff.

Ecology--

McGrath falls into the general classification of lowland spruce-hardwood forest. Typical growth in this area includes black spruce mixed with tamarack, birch, aspen, and poplar. In the immediate vicinity of McGrath there are also sparce spruce stands in wetland areas with willow and alder along the banks of the river. The vegetation along the river shows a pattern or sequence of development. Willow and alder grow in the newly forming meander scrolls along the riverbank (67). White birch, white spruce, and poplar grow farther away. Finally, black spruce-muskeg vegetation grow on the higher, older parts of the meander plains.

The bogs that occur along the meander plains also form an important segment in the ecosystem. The peat bogs consist of a water-sodden mass of dead accumulations of plant growth, mostly sphagnum moss (66). This base has a vegetational cover of mosses, sedges, and low brush. Usually, bogs are relatively small and circular; however, if the bog has developed a drainage system or taken over a low slope, it may extend for several miles. The bogs are generally underlain by silt, fine sand, and organic matter, or other conditions that impede drainage.

The McGrath area provides both a winter and summer range for moose and is located near a winter range for caribou. The Kuskokwim Basin provides a habitat for some waterfowl, however it is a low density area near McGrath. Commercial hunting of fur-bearing animals is also important at McGrath. The most frequently hunted species includes marten, beaver, muskrat, mink, and fox (2).

Population and Society

Recent history of the Kuskokwim/McGrath area begins with J. S. Spurr's historic trip across the Alaska Range in the summer of 1898, followed by a trip down the Kuskokwim by canoe (67). Spurr was accompanied on this trip by W. S. Post, a topographer, who made a sketch map of the topography and geology along the route. In 1902, A. H. Brooks took a U.S. Geological Survey party across much the same route producing more detailed maps of the area. Gold was discovered in the Kuskokwim area in 1906 and the pace of activity accelerated. Prospectors flocked to the area, and in 1907, McGrath was established as a supply post at the junction of the Tokotna and Kuskokwim Rivers. The original settlement was north of the Kuskokwim and east of the Takotna, but from 1938 to 1942, the village gradually moved to the left bank of the Kuskokwim, opposite the mouth of the Tokotna River, which is its present location.

Today, McGrath has a population of more than 300 and is growing at a rapid rate. Between 1920, when the population was 90, and 1975, when the population was 296, there was an average annual population growth of 22% (68). Although the number of residents is still small, the growth is positive. In the 1970 census, the population was given as 279 with 39% of the population listed as native and 61% as non-native. At that time, the native population was about equally divided between Indian and Eskimo peoples.

A housing survey conducted in February 1977 determined that there were 82 occupied homes. Of these homes 32, or 39%, were owned by some governmental or commercial agency such as the FAA, the Bureau of Land Management, the State of Alaska, the Northern Commercial Company, and others. A study is currently underway to determine alternatives for providing utilities for 30 additional homes in McGrath. The alternatives basically concern whether to provide central or individual water and sewer facilities.

Most of the homes in McGrath are serviced from individual wells. Two government facilities, the Federal Aviation Administration (FAA) and the Bureau of Land Management (BLM) have central water systems. The FAA well is 74 meters deep (242 ft). This deep well is not troubled with icing problems; however, the water has problems with high alkalinity, hardness, color, total dissolved solids, and high iron content. In addition, natural gas comes to the surface with the water which increases the problem of water treatment and presents an often dangerous condition for handling and storage. Wells for individual homes are generally shallow, in the range of 6.7 to 12 meters (22 to 38 feet). Nearly all wells have electric pumps, although some are operated by hand pumps. These shallow wells do not generally have problems with freezing. A few homes do not have an individual water supply.

The chemical content of the well water at McGrath is not nearly as great a problem as the bacteriological content. Recent water samples taken from some private wells have shown that the water is not satisfactory as a potable water supply. The problem is in the type and condition of the waste water treatment facilities. Most of the homes are served by a leaching cesspool. Many of these cesspools have been used and abandoned so that the land will not now handle additional cesspool installations. Many homes are also served by septic tanks, however this system still requires a soil absorption system, such as a cesspool. The high water conditions that occur at McGrath every year result in a contamination problem for the shallow wells. The high water table varies from near the surface in some areas to about 4 meters below the surface in other areas. This makes contamination of the shallow wells a chronic problem.

Economy

The economy and employment patterns at McGrath have shifted from traditional pursuits, such as prospecting and trapping, to employment by the numerous government agencies that are in the area and private business. Table 22 shows the government and commercial agencies that provide most local employment.

Transportation

McGrath is served by major air carriers and barge lines. The city is not served by rail lines or roads connected to other communities.

Most of the supplies required by the city are shipped in by barge, in this case the Black Flag Barge Company operating along the Kuskokwim River out of Bethel. This means, of course, that these goods, particularly necessities such as fuel oil, must all be delivered during the short summer season. If fuel supplies are not delivered by barge in summer, they must be supplied by air tanker in the winter at much higher cost. Since McGrath is several hundred kilometers upstream near the end of the area served by barges, barge operators may choose to serve the nearer, more lucrative stops along the river. This practice leaves the most distant communities, such as McGrath, without adequate fuel supplies for winter.

Since McGrath does not have a barge terminal or pier, barges are beached and offloaded just to the east of the city. Figure 42 shows the approximate location of the offloading area. This area has a permanent fuel transfer pipeline used to offload all petroleum products to Vinasale Enterprises, the fuel sales and storage firm located a short distance away.

McGrath has an important, major inland air terminal that is a frequent stop for airlines operating between Fairbanks and coastal towns such as Bethel, or between Anchorage and Nome. The principal runway is 5,460 ft long, hard surfaced, has an instrument approach, runway lighting, and a visual approach lighting system (20). This facility will accommodate DC-3, DC-6, C9A, C-130, Boeing 707, 737, F-27, B-52, C-135, and a variety of other smaller aircraft. Although the McGrath terminal has all required fuel for these

TABLE 22. GOVERNMENT AND COMMERCIAL EMPLOYERS IN McGRATH

GOVERNMENT

U.S. Post Office

FAA Control Tower, Offices, & Maintenance Shop

Iditarod Area School, District Administrative Office

State of Alaska Fish and Game

State of Alaska Public Safety

State of Alaska Department of Fish and Wildlife

McGrath Native Village Council

General Services Store

McGrath Library

State of Alaska Airport Manager's Office and Maintenance Shop

McGrath School

State of Alaska Public Health Clinic

BLM Summer Headquarters

City of McGrath Elderly Housing Project

City of McGrath Water Treatment Building

COMMERCIAL

Alaska Commercial Company Store

Vinasale Enterprises (Fuel Sales and Storage)

McGrath Light and Power Company

McQuires Tavern

Wein Air Alaska Terminal

Magnuson Airways Office

Polar Airlines Terminal

Hub Air Service Office

Beaver Sporting Goods

MTNT Ltd. Corporate Office (Native Corporation)

Degnan's McGrath Roadhouse

Anderson's Heavy Equipment Rental Office

Don Harris Construction Company

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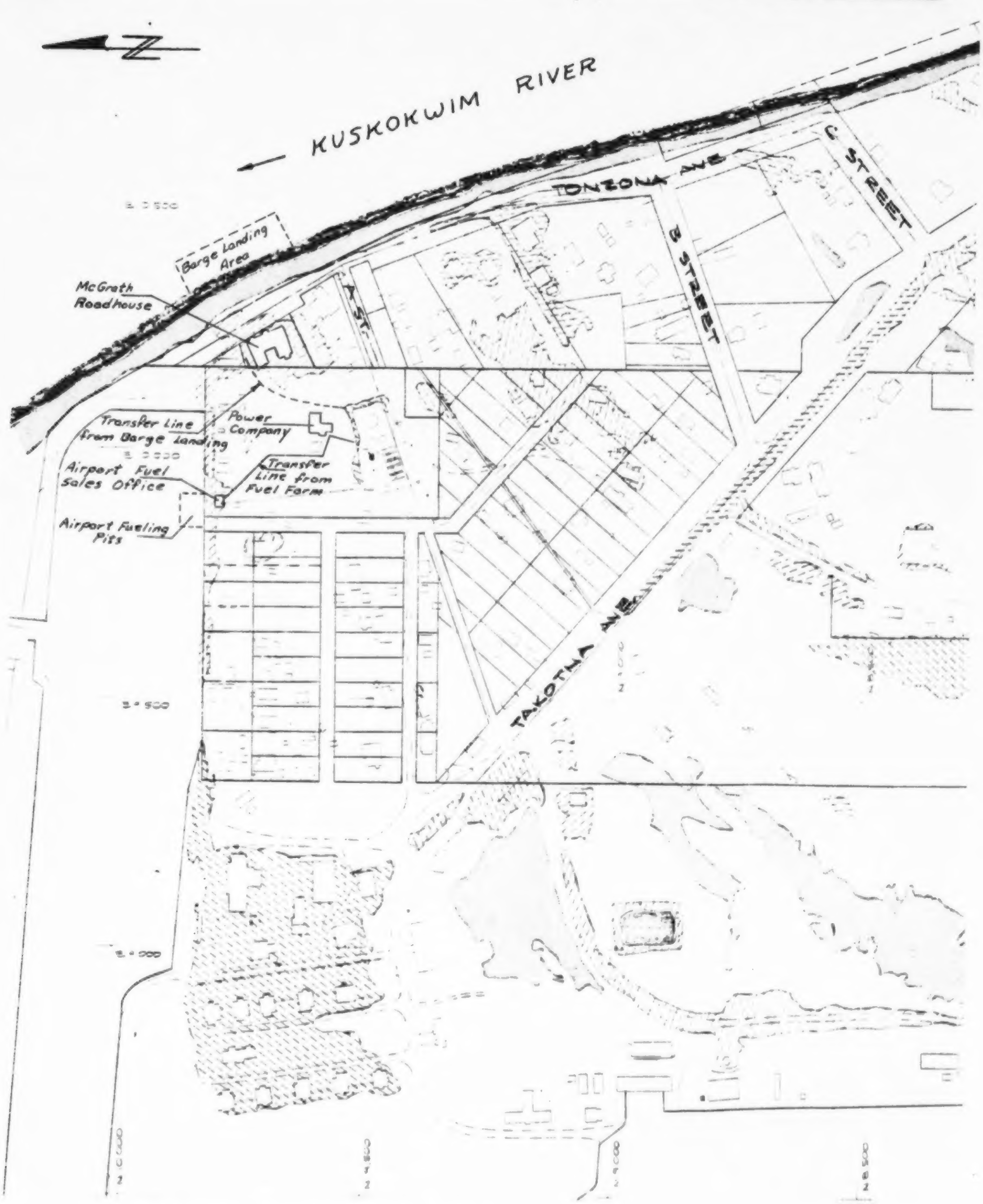

KUSKOKWIM RIVER
TONZONA AVE
C STREET
B STREET
A ST.
TAKOTNA AVE
Barge Landing Area
McGrath Roadhouse
Transfer Line from Barge Landing
Power Company
Airport Fuel Sales Office
Transfer Line from Fuel Farm
Airport Fueling Pits

Figure 42. Barge landing, the fuel farm, and the airport fueling pit at McGrath.

aircraft, it is not normally a fueling stop for the larger aircraft because the transportation costs of bringing fuel into McGrath make it expensive. McGrath is more often used as a fueling stop for smaller aircraft that must fuel to reach more distant locations. These aircraft generally require aviation gasoline. Many small aircraft are also based at McGrath so that local air traffic is often heavy, particularly in the summer season. The city also has a seadrome available but it is not attended. Table 23 shows the percent of the time the McGrath airport has been at or above specified ceiling and visibility limitations (2). Using this table it can be seen that the ceiling and visibility is greater than 1,000 feet at 3 miles, the minimum required for visual flight rules, 93% of the time. In addition it is greater than 600 feet and 1 mile 98% of the time, which is the typical requirement for a low precision instrument approach. Thus, McGrath has an air terminal that can be used nearly all of the time, and operations are not likely to be limited by ceiling and visibility conditions. Air service could be limited, however, by icing conditions, surface winds at the runway, or snow and icing conditions on the runway.

TABLE 23 CEILING AND VISIBILITY EXPERIENCE FOR McGRATH

Ceiling (ft)	Visibility (miles) in Each Case						
	≥ 3	$\geq 1\frac{1}{4}$	≥ 1	$\geq \frac{3}{4}$	$\geq \frac{1}{2}$	$\geq \frac{1}{4}$	≥ 0
≥ 1800	87	88	89	89	89	89	89
≥ 1500	89	91	91	92	92	92	92
≥ 1200	91	93	94	95	95	95	95
≥ 1000	93	95	96	97	97	97	97
≥ 900	93	96	97	97	97	98	98
≥ 800	93	96	97	98	98	98	98
≥ 700	94	96	98	98	98	99	99
≥ 600	94	97	98	98	99	99	99
≥ 500	94	97	98	99	99	99	99
≥ 400	94	97	98	99	99	100	100
≥ 300	94	97	98	99	100	100	100
≥ 200	94	97	98	99	100	100	100
≥ 100	94	97	98	99	100	100	100
≥ 0	94	97	98	99	100	100	100

Roads in McGrath are all for local travel. Besides the roads that serve the residential and commercial sections of the city, there is a single road that runs 2.7 km out of town to a radio tower.

Petroleum Development

Petroleum activities at McGrath include receiving fuels from the barge lines, fuel storage, and fuel transfer to the consumers. Figure 42 shows the details of the central portion of the city and will be used to describe fueling activities.

Referring again to Figure 42, fuels are delivered by beaching a barge in the barge landing area located right in front of the McGrath Road House. Permanent fuel transfer lines running above the surface of the ground take the fuel from that point to the fuel farm located on "A" Street. The fuel transfer lines run along the edge of the Road House to the fuel farm. The approximate location of these lines is shown in Figure 42. The sketch of these lines was obtained from a conversation with the manager of the fuel farm and an aerial photo of the area. The city power company, located immediately adjacent to the fuel farm, has an above ground storage capacity of 644 m^3 (170,000 gal) of stove oil and also has a direct transfer line from the fuel farm. An airport fuel sales office is located on the east apron of the closed east-west runway. The airport fueling pits are on the apron in front of the sales office. These fueling pits are also connected to the fuel farm by above ground transfer lines; however, these lines go underground for a distance of about 15 meters under the road that is adjacent to the fuel pits.

Vinasale Enterprises is the sole distributor of fuel for the city and virtually all fuels go through this distribution point except that some families may buy their home heating fuel directly from the barge. Table 24 shows the usual distribution of the fuels stored at the fuel farm.

TABLE 24 FUEL STORAGE AT McGRATH

Total Fuel Capacity, 1836 m (485,000 gallons)

Typical Distribution

AVGAS	80/87 Octane	133 m^3 (35,000 gallons)
	100/130 Octane	189 m^3 (50,000 gallons)
JET A		76 m^3 (20,000 gallons)
No. 1 Stove Oil		946 m^3 (250,000 gallons)
Marine		151 m^3 (40,000 gallons)

Stove oil includes the largest amount of product stored. The stove oil is used to heat residences, but the power company is the largest consumer of this product. Aviation gasoline (AVGAS) is next in order of storage volume. A great many light aircraft that need AVGAS are located at McGrath and many transient aircraft stop for fueling, which accounts for the relatively high usage of aviation gasoline. The jet fuel goes mostly to transient traffic and helicopters that operate from McGrath in the summer. Larger aircraft operating with scheduled airlines generally do not fuel at McGrath. The marine fuel is used for outboard motors and for motor vehicles.

Spill Behavior

The spill at McGrath could be more properly considered a deposit of aviation fuels that has accumulated over a long period of time below the area of the airport fuel pits. It is assumed that fuels have been lost in the fuel pits from leaking connections and valves in the fueling lines, and from small spills of fuels left in lines after aircraft servicing has been completed.

Small spills have also have occurred from the fuel samples taken from aircraft to check for water. In addition, the fuel transfer lines from the fuel farm are vulnerable to undetected damage in the area where they go under the road adjacent to the fuel pits. These lines could be damaged by frost jack, slump of normally permanently frozen ground, or leaking caused by erosion of the underground pipe. The spill in this scenario is assumed to result from a combination of these factors which, over a period of several years, results in a volume of 111.3 m^3 (700 BBL or approximately 30,000 gallons) being collected in the general area under the airport fuel pits.

The reader must be cautioned that this is a hypothetical situation postulated for the purpose of examining the appropriate spill response procedures. There is no evidence to suggest that an unsafe condition, or a potentially unsafe condition, exists at McGrath. On the contrary, there is every reason to believe that fueling operations at McGrath are excellent. On the other hand, the kind of spill described in this scenario is very common at airports in the United States, even at such well established locations as Boston's Logan airport and Kennedy Airport in New York. The problem has also been discovered at many small military bases as well. Frequently the spill is not discovered until the accumulation of product has become large. In the case of some Air Force bases, the spill has not been discovered until several years after the base has been closed. There is no reason to believe that McGrath Airport actually has the problem described, but on the other hand, this type of spill is so common to airports that there is no reason to believe that there is no potential for it occurring at McGrath.

Vertical Movement of Oil in the Ground--

Oil spilled on soil or under soil moves down under the force of gravity and also spreads laterally (56). If the original spill is circular then as the oil moves down in the ground, the volume of the soil that is oiled is essentially a cone. The shape of the cone depends on the permeability of the soil in which the oil is moving; highly permeable soil results in a cone with a small base since the oil does not have much time to spread as it migrates downward, and less permeable soil has a cone with a large base since the oil has more time to spread laterally as it descends.

As the oil moves down in the soil, a small amount will become attached to the soil particles. In effect, the oil becomes absorbed by the soil, so that the vertical migration of a small spill will stop in a short time.

Vertical migration of oil spilled on the ground also depends on the viscosity of the oil. When a spill occurs on the ground, or underground, the immediate concern is whether the spill will migrate down to the water table. As mentioned previously; the vertical movement of the spill depends on the volume of oil spilled, the viscosity of the oil, and the type of soil under the spill. The depth of penetration of the spill can be estimated using the following expression (56):

$$D = \frac{K \cdot V}{A}$$

where

D = maximum depth of penetration in meters
V = volume of oil spilled in meters
A = area of infiltration in meters
K = a constant that depends on the soil type and the oil viscosity (values of K are given in Table 10).

If the depth of the water table at the site of the spill is known, this expression can be used to quickly determine if the spill is likely to contaminate the water supply. Consider the case at McGrath. An estimated 111.3 m^3 (30,000 gallons) of jet fuel mixed with some AVGAS has been spilled in soil that is sand and sand mixed with gravel. From Table 10 assume a K value of 40 and assume that the size of the original spill is 30 m^2. The estimated depth of penetration is therefore:

$$D = \frac{K \cdot V}{A} = \frac{40 \cdot 111.3 \text{ m}^3}{30 \text{ m}^2} = 148 \text{ m.}$$

Since wells in this area are only about 8 m deep, this spill could migrate very quickly to the water table and contaminate the water supply. In fact, even a much smaller spill would move down to this shallow water table.

Consider now how the oil moves after it reaches the water table. The moisture content in the soil increases in the capillary zone immediately above the water table and the soil becomes saturated at the level of the water table. The capillary zone may be a few millimeters thick in course soils and up to 10 cm thick in very fine grained soils. The oil can be expected to spread over the water table to a thickness that is approximately equal to the thickness of the capillary zone. Knowing the approximate volume of oil spilled and the thickness of the capillary zone, one could compute the area of spreading on the water table. This computation would be valid if all of the oil migrated down to the water table, but some of the oil remains in the vertical column of soil coating the soil and particles. The expression given below computes the area of spreading on the water table by reducing the volume of the spill by the amount of oil that is estimated to remain in the vertical column of soil:

$$S = \frac{1000}{H} \left[V - \frac{A \cdot d}{K}\right]$$

where H is the thickness of the capillary layer in mm, d is the depth of the water table, and the other symbols are as previously defined. From Table 10, the capillary layer is assumed to be 20 mm thick and the water table is assumed to be 4 m deep at McGrath. The estimated area of spreading is therefore given by the following:

$$S = \frac{1000}{20} \left(111.3 - \frac{3 \cdot 4}{40}\right) = 5550 \text{ m}^2.$$

The radius of a spill with this area is:

$$R = \sqrt{\frac{S}{\pi}} = 42 \text{ meters.}$$

This computation also shows that if the water table is shallow and the oil is spilled gradually in a small area, then the second part of the expression estimating the volume of oil remaining in the vertical column of soil ($A \cdot d/K$) becomes insignificant, in this case 0.3. Given these conditions the area of the spill on the water table can be computed by simply knowing the volume of the spill and the thickness of the capillary layer above the water table.

The expression for the area of spreading on the water table represents a relatively short term condition. For a spill that has taken place over a long period of time, the oil could migrate anywhere the water table occurs. Seasonally the water table rises and falls introducing the spilled oil to new layers of sand, soils, clay, or rock, and opportunities to migrate downslope in new directions. It is therefore assumed that for the McGrath scenario the spilled oil moves on the water table sufficiently that the water supply of several homes near the area of the spill becomes contaminated, and that the spill also finds its way to the banks of the Kuskokwim River where it slowly leaches into the water. These assumptions are made for the purpose of illustrating spill response procedures for this scenario and are not based on a more detailed hydrological study. Rather the assumptions are based on the fact that this kind of underground spill movement is common in many similar locations, and therefore is also possible in McGrath.

Finally, oil, and especially refined products, contain fractions that are soluble in water. Generally the lighter the product, the more soluble it is in water. This, of course, causes the contamination of the wells as these products reach the water table. In addition to the spilled oil moving on the water table, the dissolved parts of the product can be expected to be moving in the water table. Since the spill occurs under ground, there is virtually no evaporation until the product becomes exposed.

In the first part of this section, it was noted that the spill was leaching out at the edge of the river at a rate of about 1200 liters per day. Assuming the spill volume is about 111 m^3, or 111,000 liters, it would take more than three months for all of the oil to leave by this route. Further, if the amount of oil in the spill does not increase, this rate of leaching can be expected to decrease. In addition, a drop in the water table in late summer or seasonal freezing may cause the leaching to stop entirely.

In spring, the Kuskokwim can be expected to be turbid and silty. As a result, the oil leaching out of the riverbanks is likely to become attached to the silt particles and therefore it is not likely to be visible after it enters the river. This will complicate the spill response effort for the oil leaching into the river.

Most of the spilled product in this scenario is on the water table and therefore will not be affected by evaporation; however, the 1200 liters per day that is leaching into the Kuskokwim River will be affected by evaporation.

Since the spilled product is a highly volatile mixture of fuel, fuel oil, and AVGAS, evaporation can be expected to reduce the size of the spill on the river rapidly. The rate of evaporation on the open water depends on the area of the slick exposed, the temperature of the spilled oil, and the wind conditions. The temperature and wind conditions can be determined from records; the slick thickness must be estimated. Several researchers have found that when oil is free to move on open water, spreading ceases after a certain minimum thickness is reached. By correlating empirical equations with observations, this thickness has been found to be 0.0254 mm (69). Using this estimate, a recorded average air temperature of +12°C for early June, an average wind velocity of 5.2 knots, assuming that the spilled product has characteristics similar to winter diesel fuel, and entering Figure 22 with the appropriate value for KAt, one can determine that after one day only 16% of the product remains, and that after two days it is gone. Of course the slick thickness and area exposed cannot be known precisely; however, the computation emphasizes the fact that evaporation of this spill on open water occurs quickly. If the product is constrained from spreading in back-water areas or is contained by a boom, the evaporation would occur more slowly. For example, using the same environmental conditions and a slick thickness of 0.25 mm, 54% of the product would remain after one day, 25% after five days, and 20% after seven days. In any case, evaporation would still be removing the spill from the river quite rapidly. Additional computations of evaporation rate will be presented later in the spill response methods section of this study.

Problems in Projecting Oil Spill Behavior

The methods of predicting oil movement down into the ground are basically sound, but the necessary input parameters are often not well known. This, of course, results in inaccuracies in predicting the oil spill movement. Consider for the moment Table 10 in Section 5 of this study. This table shows the physical parameters that can be used to predict the vertical migration of oil down into the ground. The values of the constant K in this table are essentially a measure of the absorption of the soil for a particular type of oil. These values of K depend on the oil type, the soil type, and the oil viscosity, which is generally most directly controlled by the temperature. The values given in Table 10 are typical for the conditions described, but they are probably not nearly specific enough for accurate calculations. Soil types are highly variable--this table only lists five types of soil. If values of K for a great many soil types were available, and if the soil type could be identified at the spill site, then the vertical movement of oil in the soil could be predicted much more accurately. These comments also apply to the depth of the capillary zone listed in Table 10; these values must also be known more accurately. The developers of these equations are likely to say that a complete study of the soil must be performed at each individual site before these equations can be applied with any degree of confidence. This would be ideal, but for spill situations it is not practical. It seems clear, however, that if highly detailed tables for many soil types were available, with a specific description of each soil type so that it could be identified in the field, the computations for vertical movement of oil into the soil would be much more accurate. This work could be performed and the results compiled in a handbook for predicting spill behavior in the field.

The other problem identified in predicting spill behavior in this scenario involves determining the area of the spill that is exposed for evaporation, or considering it in another way, determining the slick thickness. The evaporation curves presented in this study are likely to be quite accurate providing the input parameters are accurate. Temperatures and wind speeds are generally known or can be estimated from records. The most questionable input parameter is the slick thickness. More work needs to be done to permit the thickness to be measured, or for studies and contingency plans, for the slick thickness to be estimated based on other system variables.

SCENARIO 4 - TANK TRUCK SPILL

The Spill

In late July an oil tank truck was proceeding up the Haul Road from Fairbanks to Pump Station No. 6 near the Yukon River. The spill report filed later indicates that the driver stopped at Livengood for dinner before continuing on the more difficult part of the all gravel road to the north. The road north of Livengood is marked with sharp curves and steep grades. As a result, this stretch of road has become known as one of the most treacherous in the state and is the site of frequent accidents. As the driver became fatigued, he began to have problems with the curves and slopes. Crossing the Hess Creek, he noticed a log jam and the water level was fairly high from recent rains. The grade on the north side of the Creek seemed to be more difficult to handle than usual, particularly when the driver was beginning to feel drowsy.

Within six hours the pipeline surveillance flight spotted the tank truck overturned along the Haul Road to the north of Hess Creek. About 30,000 liters of diesel fuel had spilled from the truck onto the grass and moss-covered boglands on the face of the slope. Evidently the driver had fallen asleep and hit the soft shoulder about 1 km up the road from the turn after the river crossing. The truck turned over rupturing the larger of the two trailer tanks. Federal and State authorities were promptly notified and the cleanup effort began.

The Spill Environment

Climate--

The Livengood-Hess Creek area of Alaska is in the Continental Climatic zone. The average yearly temperature in this area is about -4°C, with temperatures commonly ranging from -23°C in December to 15°C in July. Temperature extremes have reached -47°C in winter and 32°C in summer. The seasons do not change abruptly; the temperature changes gradually through the year, with May, June and July being very warm in summer, and December, January and February being very cold.

Precipitation averages about 323 mm per year, with the heaviest precipitation occurring in the summer months of June, July and August. Snowfall reaches a maximum mean value of 229 mm in December, with the maximum amount of accumulated snow on the ground appearing in February.

The predominant wind direction is northerly throughout the year except in June, July and August when it changes to the southwest. Wind velocity averages between 2.4 and 6.2 knots with the highest winds occurring in May. Table 25 summarizes climatic information for the Hess Creek area.

Topography--

Land Features--The spill area for this scenario is located in the Yukon Tunana Upland Region of Alaska, between the Yukon and Tanana Rivers.

TABLE 25. CLIMATIC DATA FOR LIVENGOOD/HESS CREEK AREA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature (°C)												
Highest	-2.2	10.0	8.9	18.9	29.4	31.7	32.2	29.4	24.4	17.2	8.9	3.3
Avg. Max.	-14.4	-17.2	-8.9	3.3	13.3	21.1	22.2	18.3	11.7	-0.6	-13.9	-19.4
Avg. Min.	-27.8	-24.4	-14.4	-10.0	0.6	6.7	7.2	6.1	0.0	-8.3	-20.6	-26.1
Lowest	-47.2	-46.7	-44.4	-37.2	-20.5	-5.0	0.0	-4.4	-14.4	-28.8	-41.1	-45.6
Precipitation (mm)												
Mean	10.2	10.2	12.7	7.6	22.9	45.7	50.8	73.7	35.6	20.3	17.8	15.2
Maximum	15.2	17.8	45.7	25.4	45.7	106.7	106.7	127.0	109.2	43.2	45.7	35.6
Snowfall (mm)												
Mean	152.0	127.0	178.0	50.8	25.4	--	--	--	--	178.0	203.0	229.0
Maximum	330.2	305.0	558.8	279.4	50.8	--	--	--	50.8	330.2	457.2	482.6
*Average Wind												
Speed (knots)	2.4	3.2	4.1	5.3	6.2	5.8	5.3	4.9	4.9	4.4	3.2	2.5
Direction	N	N	N	N	N	SW	SW	SW	N	N	N	N
*Obstructions to Vision												
Fog (% of Month)	18.0	12.0	3.0	1.0	0.8	0.7	3.0	4.0	4.0	5.0	10.0	21.0
Blowing Snow	0.2	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
*% Days With 50% Cloud Cover	58	61	55	64	68	74	76	78	75	74	62	62
*Days with Heavy Fog	5	2	1	-	-	-	1	2	2	2	1	4
*Average Snow Depth (mm)	444.5	566.4	469.9	223.5	2.5	0.0	0.0	0.0	Trace	48.3	172.7	294.6

* Records for Fairbanks Airport.

The Hess Creek area is about 16.5 km north of Livengood along the Richardson Highway. Figure 43 shows the tank truck spill site on Hess Creek.

The topography is characterized by rounded ridges which trend northeast to east at altitudes of 610 to 915 m above the adjacent valley floors. Peaks rise to 1525 m in this region. The valleys are generally flat, alluvium covered, and 400 to 1600 m in width. The White Mountains rise along the eastern boundary of the region and the Ray Mountains border to the west.

Inland Waters--The Livengood area is drained by many small rivers and creeks which run along the base of steep hills and mountains. The Hess Creek is a relatively large stream which meanders in a wide, marshy valley, approximately 500 meters wide where the highway passes over the riverbed. Oxbow lakes are common in this region.

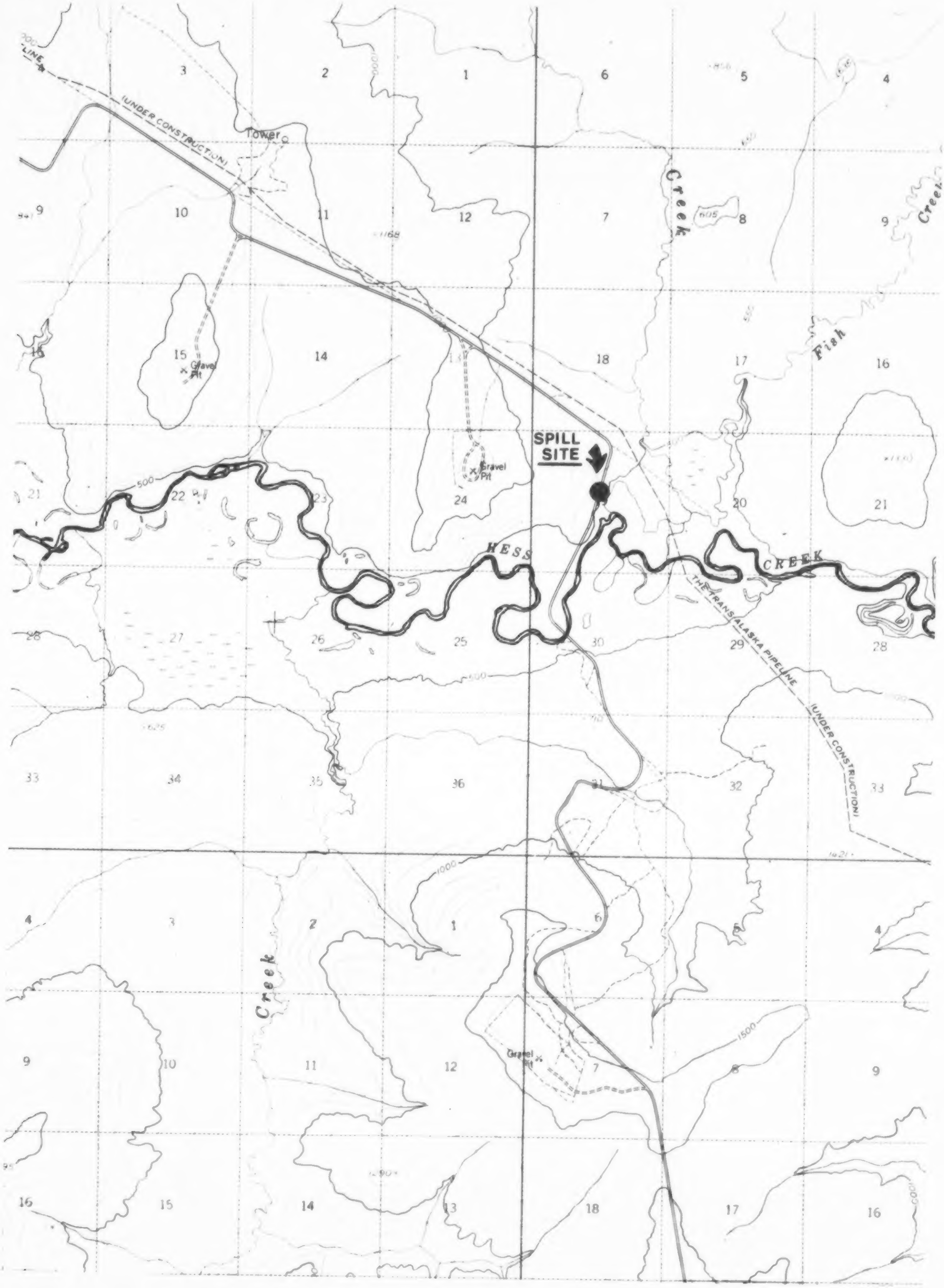
Hydrographic data for Hess Creek is presented in Table 26. Hess Creek is frozen solid with no flow under the ice in December, January, February, March and April. In late April, rising temperatures begin the spring thaw and breakup occurs in early May. Peak flow in the river due to run-off continues through most of the month and tapers off in June. Maximum average flow velocity in the creek is about 1.7 knots in May, dropping to about 1 knot from June through October. Log jams are reported to be prevalent in Hess Creek near the highway crossing in July and August. Surface ice cover begins to form in October and complete freezeup of the river occurs in November.

Geology--The terrain of the region has a variable slope. Most of the area between Livengood and Hess Creek has steep, loamy hills overlying a deep substratum of shattered bedrock. Other isolated patches of silty loam appear in more level areas. From Hess Creek south toward Fairbanks the soil has increasing amounts of gravel. A major area of stabilized sand dunes is also located in and around the Livengood area.

Permafrost is discontinuous throughout the region. Ice wedges, which are common in the area, are relatively unstable. That is, they are barely growing or not growing at all. Since the ice wedges are not growing, they are often hidden by recent sediment deposits. Both the discontinuous permafrost and the ice wedges make construction of structures and roadways difficult and necessitate constant repair when earth movement or ice melting occurs.

Ecology--The tank truck oil spill is assumed to occur in a narrow band of low brush - bog muskeg in the Hess Creek flood plain surrounded by lowland spruce-hardwood forest.

The low brush-muskeg area extends along the shores of the Hess Creek in a band about 5000 meters wide. This area is normally too wet to support tree growth. Bog vegetation consists of varying amounts of sedges, mosses, bog rosemary, rose, resin birch, dwarf Arctic birch, Labrador tea, willow and berry bushes. Table 27 lists the major plants of the low brush, bog-muskeg community (3).



SPILL SITE
HESS CREEK
Creek
Fish Creek
Creek
Creek
Tower
Gravel Pit
Gravel Pit
Gravel Pit
(UNDER CONSTRUCTION)
THE TRANS ALASKA PIPELINE (UNDER CONSTRUCTION)
LINE
500
1000
1500
3
2
1
6
5
4
9
10
11
12
7
8
9
15
14
13
18
17
16
21
22
23
24
20
21
28
27
26
25
30
29
28
33
34
35
36
31
32
33
4
3
2
1
6
5
4
9
10
11
12
7
8
9
16
15
14
13
18
17
16

Figure 43. Tank truck spill site on Hess Creek.

TABLE 26. HYDROGRAPHIC DATA FOR HESS CREEK NEAR LIVENGOOD

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Width (m)	4.4	4.4	4.4	4.4	29.8	21.3	17.5	17.0	24.2	10.0	7.3	4.4
Area (m^2)	1.9	1.9	1.9	1.9	74.9	33.1	26.5	18.6	21.6	4.3	0.9	1.9
Mean Velocity (knots)	0.0	0.0	0.0	0.0	1.7	0.9	0.9	1.1	1.1	0.9	0.4	0.0
Discharge (m^3/s)	0.0	0.0	0.0	0.0	87.2	15.9	15.2	20.6	10.3	2.3	0.2	0.0
Water Temperature (°C)	0.0	0.0	0.0	0.0	4.7	11.1	13.1	13.2	4.9	0.1	0.0	0.0
Remarks	Comp. frozen	Comp. frozen	Comp. frozen	Comp. frozen	Break-up*	Clear	Log Jams	Log Jams	Clear	Freeze-up	Ice Cover	Comp. frozen

*Breakup occurs in steps:

(1) Mid ice breaks first, forming channels in the ice

(2) Remaining ice breaks from shoreline

(3) Ice flows for a few days along creek

TABLE 27. PLANTS OF THE LOW BRUSH, MUSKEG-BOG COMMUNITY

TREES

Black spruce
Tamarack

SHRUBS

Labrador tea
Crowberry
Willows
Bog cranberry
Blueberries
Roses
Resin birch
Dwarf birch
Bog rosemary
Alders
Soapberry
Cassandra

GRASSES AND SEDGES

Sedges
Rushes
Cotton grasses

MOSSES AND LICHENS

Mosses
Lichens

The Hess Creek region is a breeding ground for many types of mammals and birds. Moose, bear, and wolves use the shorelines of the creek for winter grazing.

Many birds also nest in the region. Table 28 summarizes the major animal species of this area. The peregrine falcon and the trumpeter swan, both endangered species, occur in this area of interest.

Aquatic life in the creek includes benthic invertebrates such as mayflies, caddisflies, midges and stoneflies and fish such as chum salmon, silver salmon, king salmon, Arctic grayling, whitefish, northern pike, lake trout, inconnu and cisco.

Population and Society

The Livengood-Hess Creek area is located about 90 km northwest of Fairbanks, the second most populated city in the state. The Fairbanks-North Slope Borough has 45,864 residents of which 90% are white and 57% are male. The preponderance of men is a result of the importance of Fairbanks as a residence for workers during the construction of the TransAlaska Pipeline System. Livengood itself is a basically non-native town of about 25 year-round residents and 75 summer residents. The nearest native community is about 90 kilometers southwest near Minto.

Economy

Livengood and the surrounding region has always been a mining area. Many small placer mines, run by two or three individuals, dot the landscape. A large mine in the town of Livengood employs about 10 people. Other small businesses in the area include one small cafe, a general store and a small road camp set up by the State Department of Transportation. The road camp employs five people and serves to keep the Haul Road maintained. A pipeline camp ten kilometers west of Livengood is now abandoned.

The area between Fairbanks and the Yukon, which includes Livengood, is a well used trapping ground for hunters of small fur-bearing animals. Animals hunted commercially for furs include marten, lynx, wolf, wolverine, mink, muskrat and fox.

Transportation

The primary access to the spill site will be by the Haul Road since the tank truck accident occurs on this road just north of Hess Creek. The Haul Road is a secondary gravel road that is well maintained by the Department of Transportation. Currently, the maintenance group is working to eliminate dangerous curves in the road, but this work has not progressed to areas north of Livengood. These northern roadways have sharp turns and steep grades that frequently cause traffic accidents. The particular curve in this scenario is a right-hand curve on a steep uphill grade as the truck travels north from the Hess Creek crossing.

TABLE 28. ANIMALS OF THE LOW BRUSH, MUSKEG-BOG COMMUNITY

MAMMALS

Masked shrew
Snowshoe hare
Northern bog lemming
Meadow vole
Tundra vole
Coyote
Gray wolf
Black bear
Grizzly bear
Ermine
Wolverine
Lynx
Caribou

BIRDS

Common loon
Arctic loon
Red-necked grebe
Horned grebe
Whistling swan
Trumpeter swan
Canada goose
Mallard
Pintail
American wigeon
Northern shoveler
American green-winged teal
Canvasback
Lesser scaup
Oldsquaw
White-winged scoter
Surf scoter
Peregrine falcon
Lesser sandhill crane
Greater yellowlegs
Lesser yellowlegs
Northern phalarope
Common snipe
Mew gull
Bonaparte's gull
Arctic tern
Hawk-owl
Tree swallow
Gray jay
Common raven
Bohemian waxwing
Rusty blackbird

Two airfields serve the Livengood area and can be used in cases of emergency. One airfield is located in the town itself. This field is unattended and has a 1000 foot (300 m) runway that is rutted and soft when wet, and has brush cover along the shoulders. The other airfield is in the former pipeline camp 10 kilometers west of town. This field is attended during the daylight hours by security personnel and can handle aircraft able to land on 2500 feet (760 m) of gravel runway.

Petroleum Development

Very little storage or production of petroleum occurs between Fairbanks and the Yukon. Small tanks are used by year-round miners for storage of home heating oil, and gasoline and diesel oil are stored for machinery operation. Petroleum products are brought into the area by tank trucks from Fairbanks using the Haul Road.

Spill Behavior

The low brush-bog muskeg area where the oil is spilled is generally wet and soft during the summer months. The peaty soil is known to contain about three times as much water as soil (66). Knowing the amount of moisture in the soil is one of the keys to accurate spill behavior prediction in this case. Although the area is typically moist during July, this condition could vary from year to year, or even from week to week. Recognizing the hazards of making predictions in this case, it will be assumed that the ground is wet. This will result in a situation in which the spill is moving down a slope rather than being absorbed by the soil.

Oil spill behavior is developed in this section in four steps: determining the way in which the oil leaves the tank truck, computing the way in which the spill moves down the slope, computing the movement of oil in Hess Creek, and describing the way in which the spill evaporates.

Spill from the Truck--

The first of the two tank trailers, which is the only one assumed to rupture, carries 37.85 m^3 (10,000 gallons) of light diesel fuel. Of this volume, it is assumed that about 80%, or 30.28 m^3 (8,000 gallons) is spilled. Assume that the tank has a diameter of 2 m and that as the tank empties, the average height of the liquid above the hole is 1 m. The velocity of the flow from the tank is given by:

$$v = \sqrt{2gh}$$

where v = velocity of flow (m/sec)
g = acceleration due to gravity (9.81 m/sec).

In this case:

$$v = \sqrt{2 \times 9.81 \text{ m/sec}^2 \times 1 \text{ m}} = 4.4 \text{ m/sec}.$$

To determine the volume flow rate, assume the tank is ruptured by a hole 30 cm long and 1.5 cm wide. The volume flow rate is therefore equal to the velocity of the flow times the area of the opening:

$$\text{Volume flow rate} = \frac{4.4 \text{ m} \times 30 \text{ cm} \times 1.5 \text{ cm} \times 1 \text{ m}^2}{\text{sec} \times 10^4 \text{ cm}^2} = 2 \times 10^{-2} \text{ m}^3/\text{sec}$$

Since the volume spilled is 30.28 m^3, the time required for the tank to empty is:

$$\text{Time to empty} = \frac{30.28 \text{ m}^3 \times 1 \text{ min}}{2 \times 10^{-2} \text{ m}^3/\text{sec} \times 60 \text{ sec}} = 25 \text{ minutes.}$$

Spill Movement Down Slope--

The volume rate of flow down a slope is given by (63):

$$Q = \frac{g\, w\, \delta^3 \sin\beta}{3\mu}$$

where:
w = width of the slick (cm)
δ = film thickness (cm)
μ = viscosity (stokes, cm^2/sec)
β = slope angle of the terrain with the horizontal.

For an air temperature of 15°C, the viscosity, μ, of the spilled product is 7 centistokes or 7×10^{-2} cm^2/sec. A chart of the spill area shows that a 100 foot elevation change occurs within a horizontal distance of 750 feet; therefore, β is the angle whose tangent is 100/750, or $\beta = 7.6°$. Assuming a film thickness of 4 mm (0.4 cm), rearrange terms, and computing the width of the slick flowing down the hill:

$$w = \frac{3\, Q\, \mu}{g\, \delta^3 \sin\beta}$$

$$w = \frac{3 \times 2 \times 10^{-2} \text{ m}^3/\text{sec} \times 7 \times 10^{-2} \text{ cm}^2/\text{sec} \times 1 \text{ m}^2}{9.81 \text{ m/sec}^2 \times (4 \times 10^{-3})^3 \text{ m}^3 \times 10^4 \text{ cm}^2 \times \sin 7.6°} = 5.1 \text{ m.}$$

The width of the slick moving down the slope is then 5.1 m, or about 16.7 ft.

The calculations presented above will yield a precise result under idealized conditions; however, some of the conditions required by the equation cannot be predicted accurately. For example, the slope angle is taken from the general trend to the land observed from a USGS chart. The local slope of the ground could be considerably different from this general trend. Also, this calculation assumes an oil film thickness of 4 mm. Mackay (63) reports that as a result of tests of oil moving over ground, he would expect an oil film thickness of 1 to 5 mm for oil having a viscosity of 1 centipoise, and 10 to 50 mm for oil having a viscosity of 1000 centipoise. The viscosity of the spilled product in this scenario is taken to be 7 centistokes, which for oil having a density of 0.850 g/cm^3, is equivalent to about 6 centipoise. This is close to the 1 to 5 mm range described by Mackay. The film thickness could even be assumed to be somewhat thicker based on Mackay's observations. This would result in having a narrower path as the spill moved down the slope. Assuming a 4 mm thickness is more conservative; that is, the resulting slick is somewhat wider. This slick width is only slightly wider than the estimate provided by Alaska state spill control specialists in Fairbanks.

The width of the slick could also be varied by other local conditions. For example, if the spill followed natural drainage channels on the ground, the slick would likely be much narrower. Also, no absorption by the ground is assumed because the ground is most likely to be wet and the spill would move on the surface. If absorption were a factor, the width of the spill would be smaller and less oil would reach the stream.

Consider now the rate at which the oil flows down the slope. The velocity of the spill down the slope is given by (63):

$$v = \frac{g\ \delta^2\ \sin\beta}{3\mu}$$

$$v = \frac{9.81\ \text{m/sec}^2 \times (4 \times 10^{-3}\ \text{m})^2\ \sin 7.6° \times 10^4\ \text{cm}^2}{3 \times 7\ \text{cm}^2\text{/sec}}$$

$$v = 9.9 \times 10^{-3}\ \text{m/sec.}$$

At the assumed spill location, the truck is 152.4 m from the river, therefore the time required for the spill to reach Hess Creek is:

$$T = \frac{152.4\ \text{m} \times 1\ \text{min} \times 1\ \text{hr}}{9.9 \times 10^{-3}\ \text{m/sec} \times 60\ \text{sec} \times 60\ \text{min}} = 4.3\ \text{hours.}$$

Spill Movement in Hess Creek--

In July Hess Creek has an average width of 17.5 m and an average velocity of 0.9 knots. These factors determine the maximum area that the spill can cover after it reaches the creek.

Evaporation--

The spill evaporation schedule can be considered in two steps: Oil evaporating from the ground and oil evaporating from the water on Hess Creek. First consider the oil evaporating from the ground. The dimensions of the spill on the ground are:

Width = 5.1 m

Length = 15.2 m

Depth = 4 mm.

The volume of oil on the ground is then:

$$V = 5.1 \times 152.4 \times 4 \times 10^{-3}\ \text{m}^3 = 3.1\ \text{m}^3.$$

The oil on the ground does not evaporate in the same way as oil on other flat surfaces. Assume that of the 4 mm film, the top 1 mm evaporates according to the standard schedule, and the bottom 3 mm stays as it is. To determine the evaporation rate, the following average conditions for July at Hess Creek are used:

Air Temperature = 15°C

Water Temperature = 13°C

Wind Velocity = 5 kts.

The oil density is taken to be 0.85 g/cm^3.

Using these conditions and the evaporation curve for winter diesel given in Figure 22, the following shows the estimated evaporation rate for the oil remaining on the ground:

Day	% Remaining
1	55
2	48
3	44
4	40
5	35
6	33
7	30

Consider now the evaporation of the oil from Hess Creek. The evaporation from the creek can be divided into two phases: the first phase consists of the oil spreading on the water to reach equilibrium thickness, and the second phase consists of the oil reaching equilibrium thickness on the water.

$$\begin{aligned} \text{Total volume spilled} &= 30.28\ \text{m}^3 \\ \text{Amount remaining on ground} &= \underline{\ 3.10\ \text{m}^3} \\ \text{Amount in Creek} &= 27.18\ \text{m}^3 \end{aligned}$$

The stream velocity is 0.9 knots or 1.7 km/hr. Assuming, as before, a slick equilibrium thickness of 0.0254 mm, and a stream width of 17.5 m, the time required to reach equilibrium thickness is:

$$T = \frac{27.18\ \text{m}^3}{17.5\ \text{m} \times 0.0254 \times 10^{-3}\ \text{m} \times 1.7 \times 10^3\ \text{m/hr}} = 36\ \text{hours.}$$

During the 36 hours assume the slick thickness is, on an average, twice the equilibrium thickness. Using Figure 22, only 5% of the spilled oil can be expected to remain at the end of 36 hours, and all of the spilled oil would be gone from the water in two full days.

Problems in Projecting Oil Spill Behavior

Predicting the movement of oil spilled from a tanker over highly variable terrain is a difficult task. The movement of the oil depends on the slope of the ground, the local relief, the type of soil, the type of vegetation, the amount of moisture present in the soil, and the type of oil spilled.

The slope of the ground is important in determining how the oil will move; however, many other features are also important. The local topography that must be considered in addition to the slope includes obstructions to flow, natural drainage features that may direct the flow or limit the spreading during flow, and low spots that may collect the spilled oil. In many cases the irregularities in the terrain may have a more significant effect on the movement of the oil than the slope considered alone.

The type of soil in the area of the spill is also significant in predicting spill behavior. Some soils may be highly absorptive of oil while others may not be. The absorptive properties of the soil must be linked with the moisture content. A soil that is highly absorptive when it is dry can absorb very little oil when it is saturated.

Local vegetation also affects the movement of spilled oil. Some types of vegetation may substantially obstruct the flow of oil, even on a steep incline, and some types of vegetation may absorb the oil. The effects of vegetation may also be expected to be seasonal - dried vegetation may absorb oil in the fall but not when it is green in spring and summer.

The number of variables involved makes accurate spill behavior prediction on land difficult. Although it would be useful to have better information on how spilled oil moves in these cases, tank truck spills are relatively small, and as a result the spill response effort generally occurs over a short period of time. Because of this, accurate spill behavior prediction is not as important as it is in the case of larger spills for which the spill response effort can span lengthy time periods.

SECTION 8

SPILL RESPONSE TECHNIQUES AND DEVICES

INTRODUCTION

This section describes and evaluates a variety of spill response techniques and devices as they apply to the four spill scenarios. Although there is some discussion of general requirements and equipment, the evaluation and description of specific equipments and techniques is limited to the technology that can be applied to this particular set of scenarios. The techniques and devices that are described in this section include those used for the following spill response functions:

- Detection and surveillance
- Containment
- Recovery
- Transfer
- Storage
- Disposal
- Logistics.

DETECTION AND SURVEILLANCE

Detection and Surveillance Requirements

For the scenarios presented in this study, the problem of oil spill detection varies from being trivial to being very difficult. For example, an oil well blowout does not generally continue long undetected. A tank truck spill, particularly when it results from a highway accident, is generally known immediately, at least to the driver of the truck. On the other hand, relatively large spills from a pipeline can occur and continue for some time without detection. In addition, spilled petroleum products may accumulate over a period of years under a fuel farm before being detected. A detection system for a blowout or a tank truck spill is not required; however, detection of a pipeline spill or a fuel farm spill requires a method of sensing a leak from the pipeline or storage tank.

The problem of surveillance of a spill is somewhat different from the problem of initial detection. Surveillance in this study does not refer to the long range surveillance a regulatory agency such as the Coast Guard performs to detect spills that may otherwise go unreported. Surveillance in this study rather refers to the effort that occurs after the spill has been detected to determine the extent and the movement of the spill.

Most oil spill surveillance work is performed by agencies such as the Coast Guard in enforcing oil spill control regulations. As a result, most of the surveillance equipment consists of high technology electronic devices designed to search out broad areas of the open ocean or other large bodies of water. These devices are generally highly complex, heavy, and expensive. They are, therefore, devices that are likely to only be employed by government agencies, and they must be mounted in large, fixed wing aircraft. Because of the platform requirements, these devices are not likely to be used for surveillance of inland spills, particularly not for small inland spills. This is not to say that these sophisticated devices would be entirely unsuitable for surveillance of some inland spills. For situations in which oil is spilled on large lakes or large rivers, some of these devices could be highly effective. In the case of a large inland spill, a Coast Guard surveillance aircraft may possibly be made available to record the progress of the spilled oil.

For this reason, some high technology surveillance devices are briefly described in this study. This discussion is not intended to suggest that these devices are recommended for use for inland spills, but rather that some could be effective if they were made available.

Table 29 reviews the detection and surveillance requirements for the scenarios considered in this study. As mentioned previously, detection of a blowout is not likely to be a problem. Surveillance around the area of the blowout will be important, however, and may continue for a fairly long period of time while the blowout is being capped. When daylight is available, the areal coverage of the oil could probably best be determined visually from an aircraft. Movement of oil into lakes and streams could also be best determined from an aircraft. Oil movement along the ground and into the ground is likely to be investigated by personnel moving on foot.

Because of the tremendous volume of oil moving through the Trans-Alaska Pipeline, detection of a leak is very difficult. Using currently available leak detection devices, the loss of up to 3,000 barrels of oil a day could go undetected until the leaking oil is spotted visually. As a result, there is a requirement for a more sensitive leak detection device for use on large pipelines. Once the spill has been detected, existing surveillance devices can be used to track its movement.

An underground spill such as is envisioned in the airport fuel farm spill may sometimes go on for years and never be discovered until the spilled oil becomes evident visually in a stream or pollutes a water supply. Unless there is massive leaching of oil into a stream or lake, the surveillance problem is generally one of mapping the accumulation of oil underground.

Finally, a tank truck spill generally occurs as a result of an accident on the road. The spill is therefore immediately known to the driver, if he survives, and generally not detected by some other method unless the driver is not able to report the spill himself. Even though the driver knows of the spill immediately, tracking the movement of the released oil in a tank truck spill may be enhanced by the use of some type of surveillance device, if the spilled oil migrates to an adjacent lake or stream.

TABLE 29. OIL SPILL DETECTION AND SURVEILLANCE REQUIREMENTS

SCENARIO	DETECTION/SURVEILLANCE REQUIREMENTS
Blowout	• Extent of areal coverage • Spreading at the oil/ground interface • Penetration into the soil • Movement in lakes or streams
Pipeline Spill	• Leak in pipe • Oil in ground • Oil under river ice • Oil on water • Oil on riverbanks
Airport Fuel Farm	• Leak in pipe • Oil under fuel pits • Oil in wells • Oil on water table • Oil in river • Oil on river banks
Tank Truck Spill	• Oil penetration into ground • Oil on water • Oil on vegetation • Oil moving in wetlands and into adjacent streams

Summary and Evaluation of Surveillance Devices and Techniques

Sophisticated surveillance devices are often not required for minor inland spills. In most cases, these devices will not be available. Table 30 shows the surveillance devices that may have some possible application for use on inland spills. Many of these devices would only be available on a large Coast Guard surveillance aircraft. If such an aircraft were available for a major inland spill, some of these devices could be very effective. Table 30 was not developed to suggest that these devices are required to accomplish the surveillance mission, but rather to indicate that some devices would be useful if they are available.

Table 30 does show, however, that visual search methods are likely to be most effective for an inland spill. Visual search would be highly effective to determine the areal coverage of a spill and plot its movement. Also, color photography would be effective to detect the spilled oil, to document its movement, and to plot the areal coverage. Infrared devices would also be useful if they are available. Infrared devices may be available on some military aircraft in addition to the Coast Guard surveillance aircraft.

A gas analyzer may be useful in some surveillance efforts. These devices come in a small, hand-held package that is easily transported and used in remote areas. These devices have the disadvantage of being subject to false contacts from the exhaust gases of internal combustion engines or any other source of smoke.

When oil has been spilled under ice or under ground, manual drilling may be the only method of plotting its coverage. The gas detector may also be used along with the drilling.

In summary, several of the high technology electronic surveillance devices would be useful in tracking the movement of a large inland spill on water if they are available. Generally, however, a surveillance would be performed visually, using photography, or using a relatively simple portable device such as a gas analyzer. When oil has been spilled under ice or under ground, drilling may be the only way to follow its movement.

CONTAINMENT

Environmental Conditions and Boom Requirements

The use of conventional oil spill containment booms in Alaska rivers presents a number of special problems. For example, a great many Alaskan rivers are frozen over most of the winter. Within a period of a very few days at breakup, these rivers suddenly become rushing torrents reaching out far beyond their normal banks and carrying a tremendous load of mud, debris, logs, and tree stumps at a high flow rate down stream. The use of containment booms in these waters presents a number of severe challenges. In the most extreme case, the use of a containment boom could hardly be

TABLE 30. SUMMARY AND EVALUATION OF SURVEILLANCE DEVICES AND TECHNIQUES

SCENARIO
(1) Blowout
(2) Pipeline Leak
(3) Fuel Farm Spill
(4) Tank Truck Spill

ESTIMATED PERFORMANCE
● Above average
◑ Average
○ Below average
⊗ Unsuitable for this application

TECHNIQUE	OPERATING PRINCIPLE	CAPABILITY	OVERALL ASSESSMENT	
UV Linescanner	Oil films are more reflective in the ultraviolet range than the background signals.	Requires good lighting and clear sky; severely limited by weather, even light haze or high humidity; subject to false contacts from vegetation.	Not likely to be employed for inland spills.	(1) ○ (2) ○ (3) ⊗ (4) ⊗
Human Eye	Oil films are perceived by their reflectance in the visible spectrum, 0.4 to 0.7 μm.	Visibility depends on oil film thickness, color of water, sky conditions, angle of observation; visibility limited by darkness and obstructions such as rain, haze, or fog.	Primary means of detection for inland spills.	(1) ● (2) ● (3) ● (4) ●
TV	Same as human eye but can be extended into IR and UV range.	Detectability depends on thickness of slick, daylight, and obstructions to vision.	When available, TV could be used to augment or enhance visual detection.	(1) ◑ (2) ◑ (3) ⊗ (4) ○
Wide Range Image Spectrometer	Measures the range of reflected light.	Requires daylight and clear skies; not as effective for thin slicks.	May possibly be used for oil on ice.	(1) ○ (2) ○ (3) ⊗ (4) ⊗
Color Photography	Same as human eye.	Can map oil slicks; limited to daylight, good visibility, favorable sun observation angle, sky color, and water color.	A primary means of detecting and recording the limits of a spill.	(1) ● (2) ● (3) ○ (4) ●
Infrared Photography	Oil has a 20 to 100% greater radiance than the surrounding water.	Primarily an energy detector performs better than normal photography in hazy conditions; limited to daylight and clear skies.	Effective but less likely to be used than normal photography because special equipment is required; IR color photography has slightly better contrast.	(1) ● (2) ● (3) ⊗ (4) ●
Thermal Infrared Line Skanner (TIRLS)	Detects the natural black body thermal emissions of oil in the 3 to 5 and 8 to 14 μm range.	Effective in darkness and haze, will not penetrate rain or clouds; local thermal structure can cause false alarms; will not detect thin films.	A good sensor for open water, less likely to be used for inland spills; has detected oil in ice.	(1) ◑ (2) ○ (3) ⊗ (4) ⊗
Forward-Looking Infrared (FLIR)	Same as TIRLS.	Same as TIRLS except provides a real-time TV display.	May be available in military aircraft; possibly will detect oil/snow mixtures.	(1) ◑ (2) ○ (3) ⊗ (4) ⊗

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TABLE 30. SUMMARY AND EVALUATION OF SURVEILLANCE DEVICES AND TECHNIQUES (CONTINUED)

SCENARIO
(1) Blowout
(2) Pipeline Leak
(3) Fuel Farm Spill
(4) Tank Truck Spill

ESTIMATED PERFORMANCE
● Above average
◑ Average
○ Below average
⊗ Unsuitable for this application

TECHNIQUE	OPERATING PRINCIPLE	CAPABILITY	OVERALL ASSESSMENT	
Passive Microwave Imager (PMI)	Measures natural microwave energy emitted/reflected by surface; emissivity of oil much higher than water.	Day/night capability in haze and fog, partially effective in clouds, rain, and snow.	Not likely to be employed inland except when it is available on Coast Guard detection aircraft.	(1) ○ (2) ○ (3) ⊗ (4) ⊗
Side Looking Airborne Radar (SLAR)	Measures reduction in backscatter at radar frequencies.	Day/night capability and in clouds or fog; hindered by heavy precipitation; detects thin films.	Not likely to be used inland except when available on military or Coast Guard aircraft.	(1) ◑ (2) ○ (3) ⊗ (4) ⊗
Multispectral Photography	Multiple cameras divide the spectral range to use differences in spectral reflectivities.	Daylight, clear weather only.	Probably effective but not likely to be available for use inland.	(1) ◑ (2) ◑ (3) ⊗ (4) ○
	NON-SPECTRAL DEVICES			
Gas Analyzer	Hydrocarbon sniffer employing flame ionization to indicate presence of volatile hydrocarbons.	Detects petroleum vapors but exhaust gases from IC engines cause false alarms; can monitor from fixed position, hand held, or mounted in aircraft.	Readily available device that can be easily employed in remote areas.	(1) ● (2) ● (3) ● (4) ●
Lineal Oil Detector	Insulated cable shielded by oil soluble material. Impedance changes as leaking oil dissolves insulation.	Permanent underground installation; may take several hours to several days to activate alarm.	Applies to pipeline situations, better in small, short lines.	(1) ⊗ (2) ◑ (3) ● (4) ⊗
Manual	Penetrate surface with drill or pole; smell or use sniffer to detect hydrocarbon.	Auger hole in ice or ground; slow, labor intensive operation limits observations to isolated points.	Reliable but difficult to map the extent of the spill.	(1) ○ (2) ● (3) ● (4) ○

considered. As the flood waters subside, some special uses of booms may be possible; however, the types of booms to be used must be chosen carefully, and the ways in which they are used must reflect a keen appreciation for the problems of the environment. This section, therefore, deals with the use of containment booms in Alaskan rivers strictly in terms of the problems involved. In reviewing the possible types of booms that may be employed, only those that show some potential for use in Alaskan rivers are considered. The only exception to this rule is that some booms that are known to be available in Alaska are also rated even though they might not normally be considered for use in this area. Although some of the booms selected for evaluation may also prove to be inadequate, the list was developed to include those that appear to have the greatest chance of success.

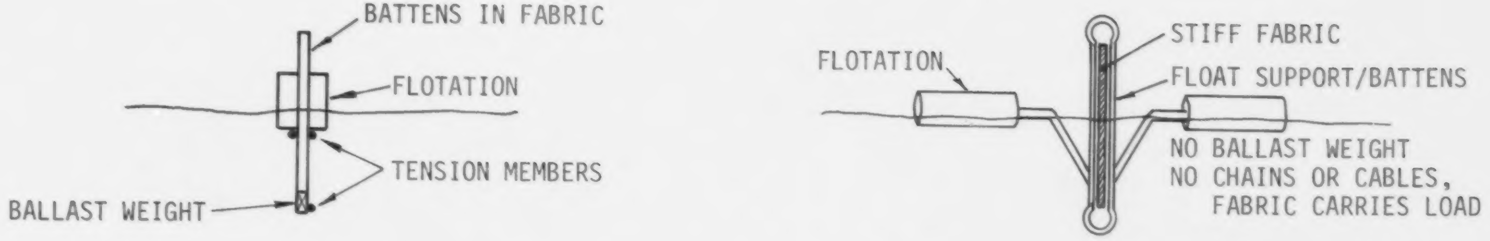
A wide variety of containment barriers or booms are commercially available for use in open water. Many of the booms currently available have been highly successful in containing spilled oil, particularly in rivers, harbors, and areas where wind and weather conditions are not severe. The usual limitations in containing spilled oil in open water include winds, waves, and currents. In cold weather regions other problems result from low temperatures, broken ice, solid ice, moving ice, and snow. In Alaskan rivers there are the additional problems of extremely swift currents and waters containing heavy debris such as logs and stumps.

Containment booms must meet a number of requirements in order to be successful. First, the booms must have sufficient structural strength to withstand the stresses imposed by the environment. In addition, they must be able to conform to the wave profile and maintain their freeboard to prevent oil from being carried over the top of the boom by wind action and waves. To do this, they must have vertical stability so that they are not flattened on the surface of the water by the action of waves, winds, or currents. For Alaskan rivers, booms must not roll over in heavy currents, fail, or lay flat permitting the oil to pass beneath.

Booms fail if the oil passes under the barrier skirt. This failure generally occurs as a result of wave action, or a combination of wave action and local currents. In Alaskan rivers, waves are not likely to be a factor; however, currents will be important to possible boom failure. It has been shown that a current velocity of about 30 cm/sec (0.6 knots) perpendicular to the boom can be considered the upper limit for successful retention of oil by the boom (70). Some researchers believe that the upper limit for a current is as much as 35 cm/sec or 0.7 knots (56). Currents in Alaskan rivers are often much higher than this, so that if booms are to be used at all, they must be deployed at an angle so that the component of the current perpendicular to the face of the boom remains in this range.

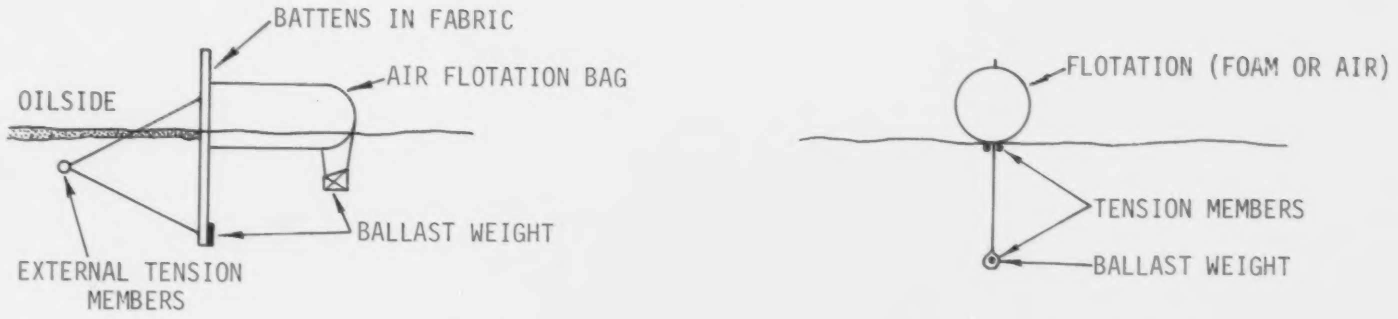
Boom Types

Figure 44 shows four basic boom designs: fence type centerline flotation; fence type outboard flotation; fence type one sided outboard flotation; and the flexible curtain type. Fence type booms use rigid battens to mechanically couple the skirt and freeboard together so that they roll as


BATTENS IN FABRIC
FLOTATION
TENSION MEMBERS
BALLAST WEIGHT
STIFF FABRIC
FLOTATION
FLOAT SUPPORT/BATTENS
NO BALLAST WEIGHT
NO CHAINS OR CABLES,
FABRIC CARRIES LOAD

(a) Fence-Type - Centerline Flotation

(b) Fence Type - Outboard Flotation


BATTENS IN FABRIC
AIR FLOTATION BAG
OILSIDE
BALLAST WEIGHT
EXTERNAL TENSION MEMBERS
FLOTATION (FOAM OR AIR)
TENSION MEMBERS
BALLAST WEIGHT

(c) Fence Type - One Sided Outboard Flotation

(d) Flexible Curtain Type

Figure 44. Boom types.

a single unit. In the flexible curtain type, the skirt is free to move independently of flotation and freeboard.

The basic centerline flotation fence type boom has the advantages of easy storage and cleaning, and additionally it is abrasion resistant. On the other hand, it has poor roll stiffness causing it to flop over easily in winds and currents. Also it does not tow well, has poor wave performance, and requires stiffeners that may chaff or break. Some of these disadvantages are overcome by the other fence type designs. The outboard flotation fence type of boom actually has the best performance characteristics in waves of any boom type because of its excellent roll stiffness due to the high induced righting moment inherent in the design. No chains or cables are required as tension members because the fabric carries the load. The disadvantage of the outboard flotation is that it can easily foul on floating debris or may collect ice in cold water. The one sided outboard flotation is designed especially for towing in a catenary in a high seas environment. This special design has limited application since it is intended for oil to be contained on the non-float side only, and does not work well in tidal situations.

The flexible curtain type boom may rely on foam or air as flotation. The round flotation cell reduces the wind drag and the free-hanging skirt allows the boom to maintain a relatively vertical attitude when following waves. As a result, it performs well in a high seas environment, although not as well as the special fence type designs that have greater roll stiffness. The inflatable booms are compact and easy to store, but vulnerable to puncture. In addition, moisture in empty air cavities may cause them to freeze closed in cold weather storage. The solid foam flotation booms have inherent reserve buoyancy, but are less abrasion resistant and are bulky to store. Both types are towable. Some flexible curtain booms have both top and bottom chain or cable tension members. These booms seem likely to be more successful in strong current situations.

The various forms of the fence type booms are most suitable for use in permanent harbor installations or offshore in the open ocean. Only the flexible curtain boom is likely to be suitable for use in Alaskan rivers, and therefore is the only type evaluated in this study.

Boom Requirements

Selection of a boom for use in Alaskan inland rivers and streams must be based upon the general performance characteristics of the boom in a swift stream and upon particular requirements unique to cold regions applications. Candidate booms must be:

1. Light, compact, and easily transportable. Access to many of the potential spill sites may be difficult and the number of personnel available to deploy a boom may be limited.

2. Easily deployable and effective at low temperatures. The boom may have to be deployed from steep river banks into a swift current, or by boat. Connectors must be easy to join, particularly in cold temperatures where men must work with mittens or gloves.

3. Designed to be as survivable as possible in swift currents that may contain ice and heavy debris. Booms could have smooth faces so that ice chunks or debris are less likely to become hung up on the boom causing structural failure. Internal flotation chambers filled with solid foam are generally more reliable because air inflatable booms may puncture and deflate. Booms should have integral tension members that allow the boom to rotate up over the ice or debris, rather than breaking if the loads become too large.

4. Suitable for use in shallow streams. Major Alaskan rivers, including the Yukon, seldom exceed 2 meters in depth. Smaller streams approach depths of 120 cm only during spring flood. Boom drafts should not exceed 1/3 the water depth to ensure containment. Using an oversized boom in shallow waters can block the flow which may result in overtopping of the boom. In addition, the boom curtain may be unable to fully deploy causing the boom to lay flat and not contain any oil. Some spill control specialists believe the ideal boom draft is about 46 cm (18 inches) even in deep water. That is because the acceleration required for water to pass under a deeper boom is more likely to cause break-away of the spilled oil. In the shallow rivers of Alaska, a draft of even less than this may be desirable.

Nearly all of the booms available commercially operate properly in calm water; however, in waves and currents, many booms fail. Since this study is concerned with inland waters, and principally rivers, waves are not a problem. High currents are, however, likely to limit the use of booms. Tests have shown that most booms fail when the velocity of the water perpendicular to the face of the boom exceeds 0.6 to 0.7 knots (56). This is a fairly conservative figure since some operators estimate the failure velocity to be 1 knot or even 1.2 knots. To reduce the velocity of the water perpendicular to the boom, the boom can be deployed at some angle other than 90° to the flow. Figure 45 shows the current velocities in knots that give a velocity of no more than 0.7 knots perpendicular to the face of the boom for various angles of deployment. This graph is useful in determining the most effective way to deploy a boom in a swift stream. The operator who believes that a particular boom will withstand a perpendicular current of greater than 0.7 knots can use Figure 45 to determine the desired boom angle to the bank by sketching in a new curve. For example, if the boom will withstand a current of 1 knot at 90°, locate the 1 knot, 90° point on the curve and sketch a new curve parallel to the original curve.

In considering the performance of a boom in a fast current it is necessary to remember that a flexible boom cannot be maintained at a fixed angle with the current. Booms deployed at an angle with the shore can be expected to take some catenary shape. When the angle with the shore becomes small, the catenary may be more like a J-shape. The curvature of the J presents a greater angle to the current and therefore has a lower speed at which the boom failure occurs. This problem may be at least partially offset by the fact that currents near the shore can be expected to be slower than those in mid-stream.

When booms do fail in fast currents, oil escaping under the boom tends to collect in the water flowing along the backside of the boom. This

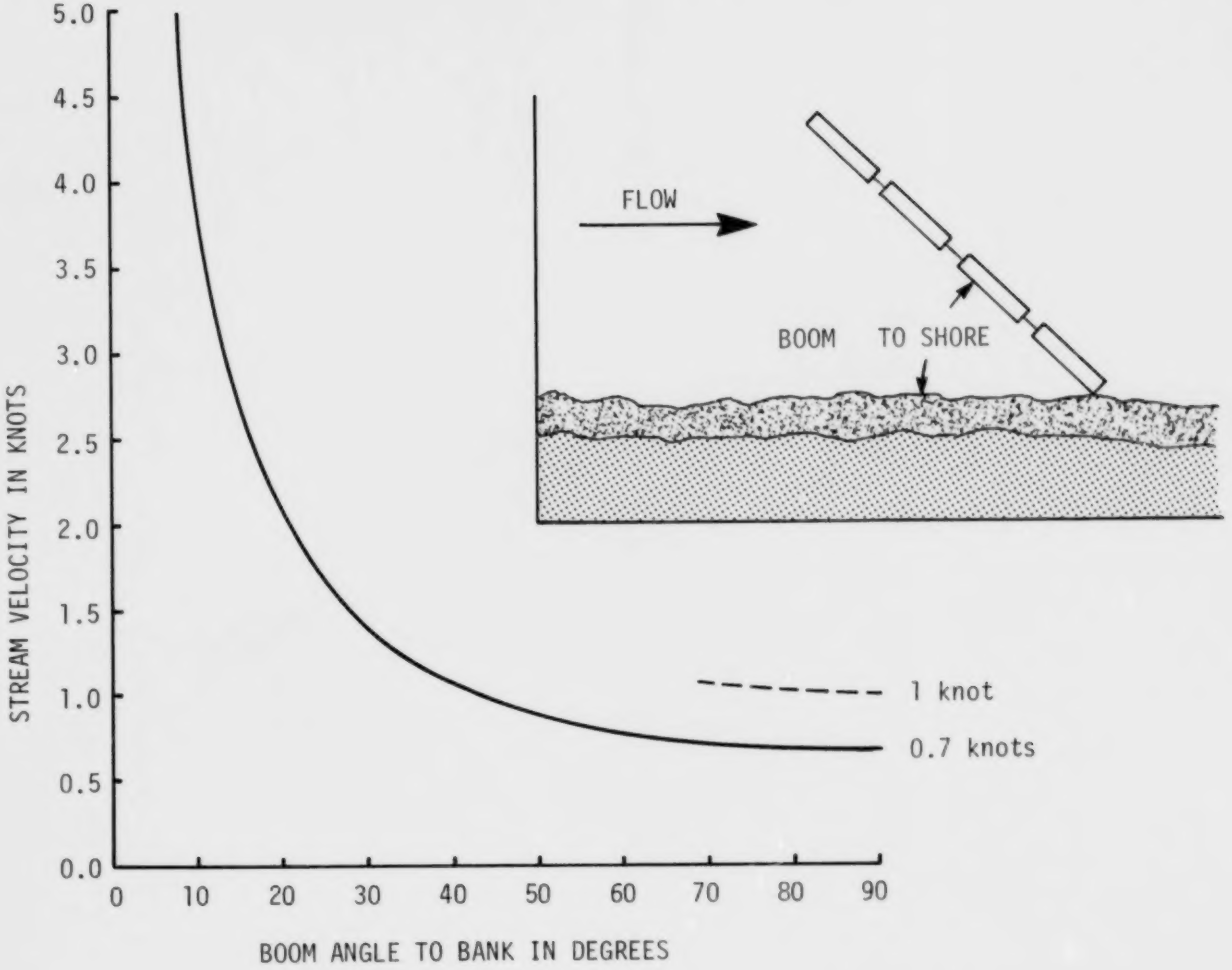


Figure 45. Boom angle to stream bank that will give an equivalent velocity of 0.7 knots perpendicular to the boom.

effect provides the spill response crew with another opportunity for containment. A second boom can be deployed just downstream from the boom that is showing failure. In some cases, a skimming device may even be successfully deployed immediately behind a boom that is failing to contain all of the oil on the upstream side.

Non-conventional booms fabricated with the materials that are available at hand may also be useful in remote locations of Alaska. For example, Figure 46 shows how logs can be chained together to improvise a boom in a remote area. The method of connecting logs shown produces a secure boom; however, other methods of connecting the logs could be used depending on the materials at hand. The boom could also be constructed with a large opening between the logs and used as a debris boom. In this configuration, one or more log booms could be deployed upstream from a conventional boom to collect ice and debris but permitting the oil slick to pass to be collected downstream by a conventional boom.

Evaluation of Available Containment Booms

The engineering specifications of a great many containment booms have been reviewed to determine which would be most suitable for use in swift rivers in remote Alaskan locations. Of the many booms considered for this purpose, most were eliminated immediately because they are intended for use in harbors. In general, fence booms are not suitable for use in the remote Alaskan rivers.

Next, manufacturers' specifications were reviewed in terms of the criteria mentioned in this section for suitability in the remote arctic river environment. In making the final selections for evaluation, weight, strength, and likely effectiveness or survivability in strong currents were among the most important criteria. Any booms whose suitability was questionable were eliminated immediately. After eliminating the booms that are not likely to be effective in Alaskan rivers, eight were selected for examination in greater detail. These eight are shown in Table 31.

Besides the handling and storage characteristics, which are important in the application of booms in remote locations, the most significant characteristic is the effectiveness or survivability in strong currents. The manufacturer's estimate of this characteristic is included in the table, but the reader must be cautioned that these numbers are not well defined, and may mean different things for different booms. For example, the manufacturer's estimate may be the number of knots of current in which the boom can survive in one case, or the number of knots of current in which the boom is effective in containing oil in another case. Some specifications show knots of current in which the boom is effective, providing it is deployed at the proper angle to the shoreline. This angle may not be specified. The most meaningful evaluation would be the number of knots of current perpendicular to the boom that could be accommodated without an appreciable loss of oil. With this information the reader could then apply the boom in a stronger current at some angle with the bank that would have the same component perpendicular to the boom.

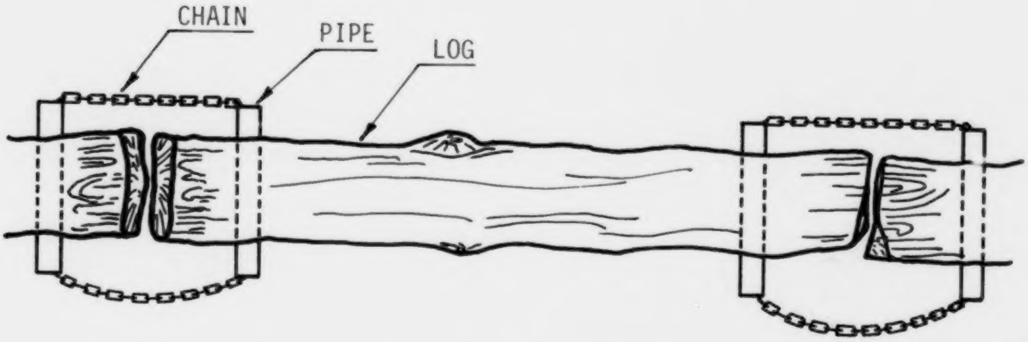

CHAIN
PIPE
LOG

Figure 46. Constructing a debris boom by tying logs together with chain strung through pipe (56).

TABLE 31 CONTAINMENT BOOM EVALUATION

MANUFACTURER/BOOM	S-STORAGE SIZE (m) W-Weight (kg/m)	STRENGTH (kg and kg/cm)	TYPE OF FLOTATION UNIT
Acme Products Co. *O.K. Corral*	S-1.5 m x 1.5 m x 3 m (152 m length) W-2.2 kg/m	2925 kg	Sealed flexible float logs; Buoyancy 10 cm dia.-8.1 kg/m 15 cm dia.-18.4 kg/m
American Marine *Simplex*	S-.94 m (30.5 m length) W-2.5 kg/m	Bottom tension 6.4 mm galvanized chain	Sealed foam, 15 cm dia.
Optimax	S-.94 m W-3.0 kg/m	Top 4445 kg Bottom 3175 kg	Sealed foam, 15 cm dia.
Centrifugal Systems, Inc. *CSI Oil Containment Boom* (Model 2 Series)	W-3.3 kg/m	4500 kg, bottom & top tension 7.9 mm chain	Sealed, flexible float logs
Enviro-Pro Industries, Inc. *River Dike*	S-2.6 x 1.8 x 1.9 (274 m length) W-3.9 kg/m	6 mm chain ballast 8 mm chain stress	Nylon cylindrical tube containing urethane floats
Kepner Plastics Fabricators, Inc. *Sea Curtain*	W-3.7 kg/m	79.7 kg/cm	Foam pellets
Metropolitan Petroleum Petro Chemicals Co. *MP Boom*	S-.84 m (30.5 m length) W-3.4 kg/m	1,182 kg (wire rope)	Solid, sealed plastic log Buoyancy 987.2 kg/m , 10.8 kg/m
Parker Systems, Inc. *PSI CONTAINMENT BOOM* Mk II Mod 0	S-2.1 m x 1.2 m x .3m/ 30.5 m length W-2.7 kg/m	4536 kg, tensile strength in chain & fabric	Sealed cylinder 15.2 cm dia, 1.83 m long
Slickbar, Inc. *Slickbar MK 10*	W-Various options 2.2 kg/m 3.0 kg/m 3.4 kg/m 3.7 kg/m	178 kg/cm	16.5 cm dia. rigid foam logs with hand holds

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● Above Average
◑ Average
○ Below Average
⊗ Not Suitable For Indicated Application

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TABLE 31 CONTAINMENT BOOM EVALUATION (CONT)

L-LENGTH/SECTION (m) D-DRAFT (cm) F-FREEBOARD (cm)	MANUFACTURER'S ESTIMATE EFFECTIVENESS IN CURRENT	CONNECTORS	OVERALL EVALUATION
L-15 m to 19 m D-30.5 cm F-15.2 cm	Add lead ballast for currents > 1 kt D-30.5 cm: 3 kts D-15.2 cm: 1.25 kts	Quick latch (type not specified or shown)	◑ Light weight, easy to store, high strength
L-30.5 m D-30.5 cm F-15.2 cm	Withstand 3-5 kts	Aluminum overlapp, slides into place, secured with single screw	◑ Light, strong, good connector; bottom tension member helps to hold oil in current; requires large volume for storage.
L-30.5 m D-30.5 cm F-17.8 cm	Withstands 3-5 kts	Same	Heavier than Simplex but probably better in strong currents because of top and bottom tension members.
L-30.5 m D-30.5 cm F-20.3 cm	-	Aluminum overlap secured with single screw	◑ Relatively heavy, good connector, shows potential for use in currents.
L-15 m or 22.5 m D-40.6 cm F-25.4 cm	Solid skirt 20 cm below water, 30 x 15 cm oval slots in skirt below for fast current; boom deployed with skirt raised; skirt dropped when boom is anchored in place	Quick connect aluminum with single pin	○ Light, compact, easy to deploy. A new product that shows potential for use in fast currents, but has not been tested.
L-30.5 m D-27.9cm F-17.8 cm	Fast current model has partly open net skirt Currents 1-2 kts	Aluminum plates connected by eyebolts and wing nuts	○ Relatively heavy but easy to deploy; poor connector, may lose flotation resulting from a tear; may not be good in strong current; compactable, can be stored in a small volume.
D-30.5 cm F-15.2 cm	1 kt or less	Aluminum slides together and screw lock	○ Relatively heavy, good connector, may not be effective in high currents
L-30.5 m 2.1 m fold to fold D-30.5 cm	1.5 kts	Slotted plastic tube slides over raised surface on face of boom; ballast chain connects with hook and ring	○ Ballast/tension member appears secure and strong; connector difficult to install particularly in cold weather
L-variable D-15.2 cm	.5 to 3.8 knots angled to flow	Quick connect aluminum with single pin	◑ Easy to deploy and handle, excellent connectors, bulky for storage, durable.

The problem in evaluating the booms has been that the literature does not show evidence of tests performed in strong currents. There are a number of reports of Coast Guard tests performed offshore, and some EPA tests performed on booms being towed to gather oil for a skimmer. However, no test has been found showing the effectiveness or design requirements for a boom deployed in a swift but shallow river. This analysis, therefore, suggests that such tests should be conducted to determine which commercially available booms are best suited to this application, or to identify the design criteria necessary to develop an effective boom for this use.

SPILL RECOVERY DEVICES

Nearly all spill recovery devices could be classified as "mechanical devices"; however, some spill response operations make extensive use of sorbents for recovery. Although the definition of mechanical recovery devices could probably be extended to include sorbents, the application and use of these substances is generally quite different from most mechanical devices. Recognizing these differences, this study separates the discussion of recovery devices into two categories; mechanical recovery devices and sorbents.

Mechanical Recovery

Types of Mechanical Recovery Devices--

A great variety of mechanical recovery devices have been developed for recovering oil from open water. These devices are generally categorized according to the way in which the oil is recovered. Types of recovery devices include weir, belt, disc, drum, and vortex skimmers, plus some devices that use a combination of these recovery methods. The recovery method describes the way that the oil is removed from the surface of the water. For example, the weir skimmer is a gravity device that collects the lighter oil from the surface of the water. Belt devices are generally oleophilic and hydrophobic; that is, they are oil absorbing and water repelling so that the belt removes the oil from the water. As the belt is drawn through the oiled water, the oil adheres to the belt while the water drips off. The belt is then squeezed or scraped to remove the oil from the belt. Disc and drum devices employ the principal that oil adheres to a special kind of surface that is rotated through the water. This surface is then scraped to remove the oil. Vortex skimmers use centripetal force to move the oil toward the center of a spinning fluid. The oil forms a pocket in the central vortex and then is pumped off. Regardless of the principal of operation, the desired result is always the same, that the oil be removed from the surface of the water as effectively and completely as possible, and with as little entrained water as possible.

The major differences in efficiency among mechanical recovery devices, generally called skimmers, are caused by the environmental conditions necessary for operation. These limitations include wave height, current speed, wind speed, cold temperatures, and obstructions on the water surface such as ice or debris. The physical properties of the oil being recovered and the physical condition of the oil in the spill also influence the effectiveness of the recovery device. Significant physical properties include viscosity, density, and surface tension. The physical condition of the oil, often a direct result of these physical properties, includes slick thickness, adherence to ice or debris, and the state of emulsification or dispersion in the water, particularly the formation of special characteristic emulsions such as the water-in-oil emulsion, generally called mousse.

A great many different kinds of mechanical recovery devices are available and most of these devices were designed for specific spill situations. For example, many large sea-going devices are available for harbor and offshore spills. Since these devices are not suitable for use in the inland areas of Alaska, they are not mentioned in this study. This study only considers those devices that are known to be available for inland use in Alaska, or those devices that show some potential for this use.

Some types of recovery devices are more adaptable for use on inland spills than others. For example, many weir devices have been designed for small inland spills. Several are described in this section. Although most belt devices are used in large, offshore skimmers, a rope-belt type is used in nearly all situations and is therefore included in this analysis. Disc skimmers come in nearly all sizes and some are suited to inland use. Drum skimmers are not currently used either inland or offshore and therefore are not included. Vortex skimmers come in a variety of sizes and one of the smaller units is described in this section. Weir, belt, and disc skimmers include the vast majority of mechanical recovery devices that are now in use, and these are the principal categories reviewed in this study.

Mechanical Recovery Requirements--

The paragraphs that follow develop recovery requirements in general terms based on the expected disposition of the spilled oil, the thickness of the layer or slick, the condition of the oil at the time the oil spill response effort is mounted, and the physical or environmental conditions that affect spill response. A later section develops a number of alternative spill response methods for each scenario. These spill response methods will show the specific application of spill response devices to each scenario. In addition, if none of the devices available appear to be adequate for the spill situation, a recommendation for additional equipment development will be made.

Oil Well Blowout--The spill behavior analysis for the oil well blowout scenario shows that most of the spill will accumulate on the drill pad. Further, about half of the oil that falls on the drill pad is expected to collect in the reserve pit. The heavy layer of oil is all expected to fall within 61 meters of the center of the drill pad, with a coating of less than 1 mm out to 152 m, and a light mist out to a distance of 928 m.

Consider the spill response requirements now beginning with the oil that has accumulated farthest from the spill site. Because of the dangers of oil vapors and natural gas that are released during the blowout, spill response measures cannot be undertaken close to the pad until after the blowout has been capped. Some distance from the pad, where the oil is falling as a mist, the oiled snow and ground could be cleaned by scraping. Although this activity may be safe, even scraping would probably not begin until after the blowout has been capped because the ground would continue to be oiled. Starting early would also require many passes to be made with the scrapers which is more likely to be damaging to the environment than a single cleanup effort. This line of reasoning assumes a blowout that has occurred in winter and is capped well before the spring thaw. If it appears that the blowout will not be capped before the thaw, then every effort would be made to remove as much oil as possible from the ground before the thaw occurs. This scenario describes a blowout that is capped well before the thaw, therefore the light coating of oil most distant from the source would be removed by scraping after the well is capped.

A heavier accumulation of oil is expected closer to the drill pad. Experience with crude spilled in the Barrow area in the winter indicates that the oil can be expected to harden within 3 to 4 hours. The expected response in this area would be to scrape up thinner coatings of oil, then thick pools of oil that had hardened could be fractured with a hammer and the pieces stored in a container until the thaw.

The drill pad and the area immediately adjacent to the drill pad can be expected to be heavily coated with oil. The initial response effort in these areas is expected to be scraping and picking up chunks of hardened oil. However, it must also be assumed that oil on the drill pad has penetrated the surface of the gravel, and in some places into the tundra adjacent to the pad. Oil that has collected in the drill pad gravel could be collected by digging a trench in the pad in what appears to be a low area. As the oil that mixed down into the gravel becomes fluid in spring, it could be expected to leach down into the trench. The trench could also be lined with plastic to improve its collection capability. Depending on the thickness of the oil in the trench, or the amount of water that accumulates with it, the oil could be collected with a weir skimmer, a belt skimmer, or a disc skimmer. Because of the geometry of the collection situation, that is, for oil collecting in a long trench, several belt skimmers would probably work best. The oil that collected in the reserve pit would not present a recovery problem.

Some of the oiled snow collected around the drill pad could be stored in the reserve pit; however, if a large volume of oiled snow is collected, some other means of disposal would be required.

Most of the oil in the area away from the pad is expected to be collected by scraping in the winter. Some of this oil would, of course, remain to be recovered after the spring thaw. After the thaw, the oiled tundra adjacent to the pad could be cleaned in a number of ways. Skimmers could be used on any accumulations of oil on water. These skimmers would probably be small light devices applied for short periods of time in isolated locations. Very lightly oiled areas could be cleaned using sorbents. In dealing with the lightly oiled areas of the tundra, it would be a matter of judgement as to whether the response effort would be more damaging to these areas than simply permitting the oil to degrade naturally. The wet tundra will be highly sensitive to the movement of response personnel.

Spill response requirements for the blowout scenario, therefore, are for weir skimmers, belt skimmers, and disc skimmers, with the emphasis likely to be on belt skimmers. Sorbents would also be important in the final cleanup operation.

Pipeline Spill--Oil from the pipeline spill has accumulated for a period of 30 days but is not discovered until breakup. Most of the oil that has been released at breakup is left to coat the shoreline as the water quickly recedes after breakup. Although most of this oil coats the beach, some may also be on stagnant wetlands or pools of water that may be present along the river bank. The oil that continues to escape in the original deposit near the pipeline will leach out into the river, but this oil is less likely to coat the riverbanks.

In cleaning the area adjacent to the river, recovery devices could be employed in the wet, backwater areas where oil has accumulated along the river. The type of device to be used would depend on the size of the slick, the thickness of the slick, and its accessibility to response equipment. If these pools of oil on the water are relatively small and isolated, with a fairly thick cover of oil (>3 mm), a small weir skimmer would probably be appropriate. If the slick is thinner, a small rotating disc would probably be better. If the oil covered a large area, a rope-belt device may be best.

The 3 mm of oil along the shoreline would be removed mechanically. Small scrapers could be used if they were available and could be used across the local terrain. In this case the beach is generally not suitable for the use of scrapers, so the oil layer will be removed by shoveling, although this method is slow and labor intensive. After the oil had been removed from the shoreline by some mechanical means, the exposed ground could also be expected to be contaminated. This oiled ground or sand could be removed to the level such that clean ground is exposed and it could possibly be cleaned using a rotary kiln burner. It could also be left exposed to permit the remaining oil to degrade naturally. This would require an on site decision to determine the least harmful or most acceptable course of action.

In the area near the original source of the spill, a large volume of oil remains in the ground providing a source of oil leaching into the river. Spill response in this area may include digging a ditch along the edge of the river to collect the oil as it leaches down. This oil could be collected with a weir skimmer, a rope-belt device, or small disc units. The type of device employed would depend on the depth of the oil collected, the amount of water that fills the ditch, and the size of the ditch. It seems likely that several rope-belt devices would be best if they could be employed in this area.

While the shoreline is being cleaned and the leaching oil is being collected in trenches, more oil is entering the river from the riverbanks and being carried downstream. Recovering this oil presents a major problem because the velocity of the stream right after breakup can be expected to be in the range of 2 to 3 knots. Because of these high currents and the debris that may be carried downstream with the spring flood currents, deployment of a boom in the stream may not be possible except in special circumstances. In some areas it may be possible to deploy a boom at an extremely acute angle to the shoreline, probably in the range of 12° to 16°. Oil could then be recovered in the pocket of the boom using a weir, a disc skimmer, or a rope-belt skimmer. The device to be used would depend on the thickness of the oil collected and on an assessment as to which device would be best in the fast current situation.

If the boom could not be streamed at an angle to the shoreline, the boom could possibly be streamed parallel to the shoreline. This deployment would be intended to prevent the oil leaching out of the riverbank from spreading across the width of the river. A fast current recovery device could possibly be employed near the downstream opening between the boom and the shoreline. This response procedure would be a stop-gap measure, considered only as better than taking no action at all in the stream, since a large amount of oil could also be expected to move past the skimmer without being recovered. If a boom were available and if this configuration proved to be reasonably successful, the available boom could be deployed parallel to the riverbank opposite the location of the greatest leaching of spilled oil toward the river.

Some areas of the river could also be diked up to collect oil if the stream velocities and conditions would permit. Water immediately behind these dams or dikes could be expected to have a relatively low velocity so that a skimmer could also be employed. Selecting a skimmer for this area would depend on the thickness of the slick and the water velocity upstream of the dam.

Fuel Farm Spill--The spill that occurs under the fuel farm at McGrath is more properly an accumulation of aviation fuels that have collected on the water table over a period of time. For recovery, one or more wells could be dug where the product is known to exist on the water table. Recovery devices would be placed in these wells to pump out the oil. There are special recovery devices designed for this kind of job. These devices will be used if they are available. If they are not available, wells with a larger diameter will be required so that some other type of skimmer, such as a floating weir, can be lowered into the hole to recover the product. The suction hose of a pump might also be lowered into the well to lower the level of water under the slick, thereby increasing the rate of flow of product into the well area for recovery. Drilling additional wells would expedite the recovery process, however since the spill is not visible from the surface, there is a problem of knowing where to drill the wells. The extent of the underground spill could be mapped by drilling a number of small diameter wells to take samples from the water table. Once the extent of the underground spill was mapped, additional larger diameter wells could be dug for the recovery devices that are available.

In addition to the wells, trenches could also be used to collect the oil from the shallow water table. Trenches would be dug in low spots and collection of oil could be improved by flushing out the soil. The oil could then be recovered with a suitable skimmer, probably a belt-rope device.

It was noted that some of the underground spill was also leaching into the Kuskokwim River. A trench could be dug along the river bank to collect and recover this product. Since this oil is seeping into the river slowly, use of sorbents would probably be adequate for recovery. A small amount of the spilled oil would probably continue to be detectable in the river. These small amounts of refined product reaching the river could be expected to quickly evaporate or become dispersed in the high volume flow. A large scale spill response effort in the river is not likely to be required.

Tank Truck Spill--This spill involves a relatively small amount of product spilled in a fairly isolated area. The part of the spill that is confined to the ground and wet areas along the side of the road could be recovered using sorbents. If some of this product was found to be pooled in a shallow wet area, a small disc skimmer could possibly be employed. That part of the spill which is finally transported down to Hess Creek could be collected with a containment boom and recovered with a small skimmer.

The foregoing discussion establishes the spill recovery device requirements in general terms. A number of spill recovery devices have been selected that show some potential for meeting these requirements. These devices will be evaluated based on the estimated scenario requirements. This will then be followed by the development of a number of specific spill response methods for each scenario.

Evaluation of Mechanical Recovery Devices

The effectiveness of a mechanical recovery device often depends on the characteristics of a particular spill response situation. That is, performance is likely to be a function of the type and condition of the spilled oil, the thickness of the slick, plus the impact of wind, wave, and current conditions on the performance of the device employed. Some mechanical recovery devices are clearly better than others; however, selecting the best device to do the job generally depends on the spill situation.

Table 32 describes nineteen mechanical spill recovery devices. These devices were selected either because they are known to be available for inland spill response in Alaska, or because they show potential for this use, particularly in the spill scenarios developed in this study. In addition to providing a physical description of each device, Table 32 also records the results of independent tests evaluating the performance of the device. These test results are not strictly comparable because the tests were performed by a variety of agencies and contractors at different times under different spill conditions. In spite of these problems, the test results are useful in comparing the performance of the selected devices. Some devices have not been subject to performance testing. In these cases reports of field use are substituted. Although field reports are only estimates of performance, these estimates are more helpful than having no data at all. Table 32 also provides a general assessment of overall recovery effectiveness and provides an estimate of likely performance in the four spill scenarios.

TABLE 32. MECHANICAL RECOVERY DEVICES

MANUFACTURER/ DEVICE	OPERATING PRINCIPLE/ DESCRIPTION	TYPE DRIVE	SIZE	MANUFACTURER'S RATING	TEST RATING	OVERALL EFFECTIVENESS
ACME PRODUCTS CO **Tunnel Skimmer* (SK-39T)	*Weir* - Floating saucer weir skimmer	Gasoline, air, or electric	1.16 m dia 62 kg	952 l/m (1.5 m head)	(1) OHMSETT Slick (mm) / Rate (l/m) / % Oil / Oil Rate (l/m) 25.4 / 224 / 46 / 103	Skims wide range of viscosities; leaves, straw chopped in impeller; will pass solids 1.3 cm.dia. High test recovery rate based on thick layer of oil. (1)⊗ (2)○ (3)⊗ (4)⊗
Mini-Floating Saucer	*Weir* - Floating saucer	Electric (110 V)	44.5 cm.sq. 23.5 cm.draft 11.4 kg.	47 l/m (1.5 m head)	(2) EC Test Slick (mm) / Rate (l/m) / % Oil / Oil Rate (l/m) Crude 6 / 18 / 9 / 1.6 Diesel 8-9 / 30 / 14 / 4.2	Good for a small, light weir skimmer, particularly on diesel, but % oil remains low. (1)○ (2)○ (3)○ (4)⊗
ALSTHOM ATLANTIC, INC. **Cyclonet* (S050)	*Vortex separator*- Spill drawn through tangential slit; suction causes centrifugal separation	Electric or IC engine	1.8 m dia 70 cm. draft 60 kg	Slick 2-3 mm, 23 l/m 8-9 mm, 142 l/m	(2) EC Test Slick (mm) / Rate (l/m) / % Oil / Oil Rate (l/m) Crude 2-3 / 138 / 3 / 4.1 9-10 / 128 / 12 / 16.6 Diesel 1-4 / 106 / 2 / 2.2 8-10 / 58 / 14 / 8.1	Device is large and heavy, draft too deep for many inland applications; % oil very low for thin slicks. (1)⊗ (2)⊗ (3)⊗ (4)⊗
BP North America **Komara Mini-Skimmer*	*Disc* - Toroidal rotating plastic discs	Hydraulic/ pneumatic	1.16 m dia. 20 cm. draft 52.2 kg	Crude 160 l/m Diesel 32 l/m	(3) EC Test Slick (mm) / Rate (l/m) / % Oil Crude 1 / 7 / 66 10 / 22 / 84 Diesel 1 / 2 / 20 10 / 10 / 60	Satisfactory for many inland applications, % oil much better than for weir skimmers; performance on thin diesel somewhat low. (1)⊗ (2)● (3)○ (4)⊗

TABLE 32 (continued)

MANUFACTURER/ DEVICE	OPERATING PRINCIPLE/ DESCRIPTION	TYPE DRIVE	SIZE	MANUFACTURER'S RATING	TEST RATING	OVERALL EFFECTIVENESS
Kebab 600	*Disc* - 5 stainless steel discs rotate on a single shaft	Electric - 120 V auto battery on 120 V AC	65 x 44 x 37 amp 10 cm. draft 12 kg	Crude Slick (mm) / Oil Rate (1/m) 10 / 10 5 / 4.7 2.5 / 1.3 Kerosene 10 / 1.8 5 / 1.4 2.5 / .8	Not Available	Too new to have test reports; appears to be rugged and suitable for use on small inland spills. (1)○ (2)◐ (3)◐ (4)◐
CENTRIFUGAL SYSTEMS, INC.						
**CSI* (Z/14E,D)	*Belt* - continuous loop swab led through an idler and cleaned in a puller-wringer	Electric or diesel	.6 m x .4 m 50 kg	26.7 1/m	(4) Field report 18.5 1/m	Mounts directly on 55 gal drum, internal transfer pump. Good for oil on water, ice-infested waters or oil under ice (has sump heater); can be used in a shallow trench. (1)● (2)● (3)● (4)○
CSI 26DP	*Belt*	Diesel	18.8 m x .8 m 495 kg	67 to 133 1/m	--	Built in pump transfers 158 1/m with 9 m head. Same performance characteristics as the smaller unit except for a higher recovery capacity. Has built in transfer pump. (1)● (2)◐ (3)○ (4)⊗
		Electric	1.3 m x .8 m 450 kg	67 to 133 1/m	--	
COASTAL SERVICES, INC.						
**Slurp*	*Weir* - self-leveling, floating weir	Vacuum pump	94 cm. x 62 cm.	Depends on pump capacity, ≈ 125 1/m	(1) OHMSETT Slick (mm) / Rate (1/m) / % Oil / Oil Rate (1/m) 25.4 / 249 / 49 / 122	High pumping rate possible, but lower capacity required to achieve reasonable % oil. High test recovery rate based on thick layer of oil. Must be attended by an operator. (1)⊗ (2)○ (3)⊗ (4)⊗

(continued)

TABLE 32 (continued)

MANUFACTURER/ DEVICE	OPERATING PRINCIPLE/ DESCRIPTION	TYPE DRIVE	SIZE	MANUFACTURER'S RATING	TEST RATING	OVERALL EFFECTIVENESS
DOUGLAS ENGINEERING *Skim Pack*	*Weir* - stationary, floating, ballasted weir	Vacuum pump	71 x 71 x 20 cm. 13 cm. draft 8.2 kg	Up to 265 1/m slick > 2.5 mm	(5) OHMSETT Slick (mm) / % Oil / Oil Rate (1/m) Heavy 3.2 16 18.4 32.0 58 95.8 Light 3.2 4.5 5.9 32.0 46 100.2	Good lightweight weir; self adjusting for variable pumping rates; low % oil for thin slick. (1) ○ (2) ◐ (3) ○ (4) ○
INDUSTRIAL & MUNICIPAL ENGINEERING **Oela - III*	*Weir* - balanced, floating saucer, stationary weir	Vacuum pump	137 cm. dia. 20 cm. draft 50 kg	Depends on pump capacity	(3) EC Test Slick (mm) / % Oil / Oil Rate (1/m) Crude 1 4 12 10 33 38 Diesel 1 6 8 10 16 14 (7) OHMSETT Lube 25.4 50 49	Effective in removing final traces of oil from water surface somewhat large,but easy to handle; rugged and reliable,one of the best weir skimmers (1) ⊗ (2) ◐ (3) ○ (4) ⊗
MORRIS INDUSTRIES *MI-2*	*Disc* - 21 rotating oleophilic discs mounted on 3 shafts that form a triangel	Electric (12 V battery)	66 cm. dia. 6.4 cm. draft 18 kg	33 1/m	(6) ACL Tests Slick (mm) / Rate (1/m) / % Oil / Oil Rate (1/m) Crude 3-6 5.0 97 4.9 8-10 5.4 98 5.3 Diesel 1-5 1.4 98 1.4 6-9 2.6 98 2.5	Performance hindered by debris;water collected as emulsion in oil, battery pack may not perform well in low temperatures. Outstanding % oil recovered. (1) ○ (2) ◐ (3) ◐ (4) ◐

(continued)

TABLE 32 (continued)

MANUFACTURER/ DEVICE	OPERATING PRINCIPLE/ DESCRIPTION	TYPE DRIVE	SIZE	MANUFACTURER'S RATING	TEST RATING	OVERALL EFFECTIVENESS
MI-30	*Disc* - 30 rotating discs, mounted as MI-2	Diesel/ hydraulic power pack	127 cm. dia. 20.3 cm. draft 68 kg	500 1/m	Crude 1-5 4.5 86 3.9 6-10 22.0 97 21.4 Diesel 1-5 4.7 97 4.6 6-10 9.1 98 8.9	Test water temp/14°C power pack operating outside at -15 to -25°C; water collected as emulsion in oil. Good rate of oil recovery, outstanding % oil recovered. (1) ⊗ (2) ● (3) ○ (4) ⊗
OIL MOP INC. **Oil Mop*	*Belt* - continuous loop oleophillic belt anchored by idler & cleaned in wringer	Electric, gasoline, diesel, pneumatic				Used extensively in cold climates; removes oil pooled on ice, under ice, & in streams and ponds. Mk I-4 can be carried by two men and mounted on a 55 gal drum. Larger units have greater recovery capacity (1) ● (2) ● (3) ● (4) ○
Mk I-4		Electric	100 x 48 cm. 86 kg	10 to 21.7 1/m		
		Diesel	100 x 56 cm. 106 kg	21.7 to 26.7 1/m		
Mk II-4		Electric	110 x 64 cm. 158 kg	10 to 2.7 1/m	(4) Nome, air temp. -35°C diesel, 7.6 1/m, 95% oil	
		Diesel		21.7 to 26.7 1/m	(6) EC Test Slick (mm) / Rate (1/m) / % Oil / Oil Rate (1/m) Crude 1-5 13 49 6.4 6-10 25 66 16.5 Diesel 1-5 5.8 83 4.8 6-10 22.5 94 21.2	(1) ● (2) ◑ (3) ○ (4) ⊗
Mk II-9	Suitable for mounting on a 2 wheel trailer	Electric Diesel	1.8 x 1.1 m 794 kg 725 kg	200 1/m	(7) EC Test Slick (mm) / Oil Rate (1/m) / % Oil Crude 1 9.8 70 5 17.3 80	(1) ◑ (2) ◑ (3) ○ (4) ⊗

(continued)

TABLE 32 (continued)

MANUFACTURER/ DEVICE	OPERATING PRINCIPLE/ DESCRIPTION	TYPE DRIVE	SIZE	MANUFACTURER'S RATING	TEST RATING	OVERALL EFFECTIVENESS
OIL RECOVERY SYSTEMS **Scavenger*	*Oil/water separator* - saucer skimmer recovers oil from open trench or water table	Electric	45 cm. dia. 5 kg	18 1/m	(2) EC Tests Slick (mm) / Oil Rate (1/m) / % Oil Diesel 4 / .5 / 100 10 / .3 / 100 (4) OS/R report Gasoline .13 to .66 1/m	Designed for unattended recovery of light refined products; used in a well, a water pump lowers water level to accelerate accumulation of product. System cloggs in fine sediments (1)⊗ (2)⊗ (3)◑ (4)○
Scavenger	*Oil/Water separator* - cylindrical probe designed to operate in a well	Electric	20 cm. dia.	133 1/m	Not available	Although test results are not available, performance may be at least that of floating saucer model. (1)⊗ (2)⊗ (3)◑ (4)⊗
SLICK BAR, INC. **Manta Ray* Rigid	*Weir* - open, semicircular floating weir	Pump suction	1.2 m dia.	454 1/m	(2) EC Test Slick (mm) / Rate (1/m) / % Oil / Oil Rate (1/m) Crude 1-2 / 173 / 1.6 / 2.8 10-11 / 115 / 11 / 12.7 Diesel 2-5 / 126 / 3.3 / 4.2 9-10 / 140 / 11.9 / 16.7 (1) OHMSETT Lube 25.4 / 59 / 44 / 26	Flexible model more common; simple, rugged, inexpensive; high pumping rate but low % oil, particularly for thin slicks. (1)○ (2)◑ (3)○ (4)⊗
Flexible	*Weir* - flexible head follows small wave patterns; good for light oil in a small stream	Pump suction	1.5 m dia. 26.3 kg		Crude 3 / 156 / 3 / 4.7 8-11 / 166 / 10 / 16.6 Diesel 2-3 / 189 / 2.1 / 4 7-10 / 137 / 10.1 / 13.8 (1) OHMSETT Lube 25.4 / 181 / 62 / 112	(1)○ (2)◑ (3)○ (4)⊗

(continued)

TABLE 32 (continued)

CODE OF SYMBOLS

Device Rating

- ● Above Average
- ◑ Average
- ○ Below Average
- ⊗ Not Suitable for Indicated Application

Scenario

(1) Blowout
(2) Pipeline Spill
(3) Fuel Form Spill
(4) Tank Truck Spill

Device Tests

(1) Performance Testing of Selected Inland Oil Spill Control Equipment, PB 279078, W. McCracken, Mason and Hanger - Silas Mason, Inc., OHMSETT test tank, August 1977.

(2) Field Evaluation of Eight Small Stationary Skimmers, EPS 4-EC-78-5, May 1978.

(3) Field Evaluation of Oil Spill Recovery Devices: Phase Two, EPS 4-EC-77-14, December 1977.

(4) Field Report. Recovery rates reported in the Oil Spill Intelligence Report or reports of contractors in the field.

(5) Preliminary Draft of OHMSETT Test of the SKIM-PAK weir skimmer.

(6) Laboratory Evaluation of Skimmers and Pumps, R. Abdelnour et al, ARCTEC CANADA Ltd for Environment Canada, April 1979.

(7) Field Evaluation of Oil Mop and Preheat Unit, EPS-4-EC-77-12, November 1977.

The reader may use Table 32 as a complete analysis document with assurance that it contains most of the information necessary, or available, to evaluate the spill response devices listed. As a supplement to this table, the paragraphs that follow will briefly describe the characteristics of the various types of recovery devices and comment on their suitability for use in the four spill scenarios.

Weir Skimmers--These devices are simple, reliable, and probably the most generally available of all the types of skimmers. Given a thick layer of oil on water (25 mm or more), these devices can recover large volumes of product with a recovery efficiency (% oil in the recovered mixture) of about 50%. When the slick thickness drops to the 3 to 8 mm range, the recovery efficiency of most of these devices drops to about 10%, and some may be much lower.

Several weir skimmers are considered to be suitable for possible application in remote areas of Alaska. The Oela-III is a popular weir skimmer with better than average performance. The Manta Ray is widely used because of its simplicity and high pumping rate, but it performs poorly on a thin slick where it shows a recovery efficiency in the 1 to 3% range. The Skim-Pack, a relatively new weir skimmer, shows high performance on thick layers of oil and fair performance on thinner layers of oil. This device has the advantages of being small, light, and easily deployed either by an operator on a wand or floating unattended.

Belt Skimmers--Two rope-belt skimmers are considered for use in this study, the Oil Mop and the CSI. Test results on the Oil Mop MKII-4 and MKII-9 show a fairly high recovery rate with excellent recovery efficiency. The smaller Oil Mop unit can be expected to have a somewhat lower recovery rate with a similar recovery efficiency. The CSI devices are similar to the Oil Mop, and although the test results are not available, these devices can be expected to perform similarly to the Oil Mop.

Oil Mop has developed a pre-heat unit to improve the device's performance when recovering highly viscous Bunker C. Tests indicate that performance is improved with the pre-heat unit (71). The pre-heat could also be expected to improve performance on oil that has become highly viscous because of low temperatures. The CSI unit has a model with a heater in its collection sump so that the device can be used in a lower temperature environment.

Disc Skimmers--These devices often have a lower recovery rate than some other skimmers, such as weir devices, but disc skimmers generally have a very high recovery efficiency. In addition, these devices can recover slicks as thin as 1 mm and maintain a recovery efficiency as high as 97%. Disc skimmers have the disadvantages of being more expensive, more complicated, more likely to break down, and more likely to become clogged with debris. The advantage of having a high recovery efficiency should not be considered lightly, however, particularly if there is a high cost for disposing of the recovered product.

Consider a hypothetical example to illustrate this point. Suppose a spill of about 76,000 liters (20,000 gallons) is being recovered with mechanical devices. Suppose further that this product is being recovered with a weir device with a recovery efficiency of 10%. This weir device must recover 760,000 liters (200,000 gallons) of an oil/water mixture in order to clean up the spill. If a disc skimmer is used with a recovery efficiency of 90%, only 84,000 liters (22,000 gallons) are recovered. If the cost of disposal is 18 cents per gallon, as it is in Maryland at the time of this writing, the cost of disposing of the product collected by the weir device is $36,000, while the cost of disposing of the product collected by the disc device is $3,960. Although the waste oil disposal problem may not be as acute in all locations, this illustration shows that the extra dollars spent on obtaining high recovery efficiency may be justified.

Vortex Skimmers--These devices are likely to be most effective in open water areas such as harbors or offshore. The Cyclonet (S050) shown here has a low recovery rate and is likely to be too large and heavy for most inland applications.

Sorbents

Sorbents are materials that soak up liquids. Ideally, an oil sorbent is a material that preferentially soaks up oil. Some natural substances have these properties and many synthetically produced substances have been developed to have these properties.

A sorbent material for petroleum products should be oleophilic, which means that it attracts oil, and hydrophobic, which means that it repels water. The ideal sorbent absorbs oil quickly and retains it. It should also absorb a large amount of oil per unit weight of sorbent and absorb very little water. The sorbent should be easy to apply and nontoxic to both the handlers and the environment. Sorbents to be used on water should be able to absorb large amounts of oil without sinking. The sorbent should be easy to recover and should be strong enough to be handled without tearing. It is generally an advantage if the sorbent is biodegradable, but it is also useful if the sorbent can be disposed of by burning. If it can be burned, it should burn without large amounts of black smoke, and it should burn without toxic fumes. Some saturated sorbents can be melted down to form a low-grade petroleum product, which provides a useful method of disposal. Sorbents should be resistant to mildew and rot in storage. Further, they should be non-flammable and not affected by temperature and humidity extremes. In arctic applications, sorbents should not be affected adversely by extremely low temperatures in storage.

Although some manufactured sorbent products are highly effective, they are also fairly expensive, particularly when they must be used on a large spill. For this reason, sorbents are used most often on small spills, in restricted areas where other recovery devices cannot be used, or for final cleanup to remove small amounts of oil left after other recovery devices have been used. Many kinds of sorbents are best used on land, particularly those types that employ particulates spread on the spill. When these sorbents are spread on land, they can be collected fairly easily; however, when particulate sorbents are broadcast on water, they may absorb the water and sink or be lost in the recovery because of the action of winds, waves, and currents.

Types of Sorbents--

Sorbents are generally classified according to the type of substance they contain. There are four classes of sorbents.

Inorganic Sorbents--These are generally mined substances such as perlite, vermiculite, glass wool, or volcanic rock. These substances are often hard to handle and have low pick-up capability. These materials can sorb about four to eight times their weight in oil, but they are generally not recommended because their use presents a number of problems (56). They are difficult to apply because they blow in the wind. Often these substances are hazardous, and operators have to wear breathing masks. Once they have absorbed the oil, they are difficult to recover. Since they may be abrasive, they may damage spill recovery devices. Further, since these substances are not biodegradable, they persist in the environment and therefore should be completely recovered.

Natural Organic Sorbents--These substances include straw, peat moss, saw dust, ground corn cobs, and other similar substances. These sorbents have often been used because they are easily available and inexpensive. The oil recovery efficiency for natural organic sorbents is slightly less than that for mineral sorbents. The natural organic products retain oil to about three to six times their weight. A disadvantage to using natural materials is that most sorb water as well as oil, and they will eventually sink. These substances are generally not as effective as commercially developed sorbents and they present a problem in collection, particularly when used on water.

Snow is another natural substance that can be used as a sorbent. Snow that has been oiled on land can be scraped up and retained to separate out the oil. Snow has also been found to have the capacity to draw oil up from the ground; therefore, after the oiled snow has been removed, more snow can be spread and removed until the snow does not take up additional oil (72).

Modified Natural Sorbents--These sorbents include natural substances that have been treated to improve their effectiveness, such as sawdust treated with silicone.

Polymeric Sorbents--These include polyurethane, polyethylene, polypropylene, and even urea formaldehyde foam. Many of these sorbents are highly oleophilic and hydrophobic and are therefore desirable as sorbents. The problem with these substances is that they may not be easily available, and they are often relatively expensive. In spite of these disadvantages, their high efficiency and potential for re-use make them attractive for use in a variety of situations.

Companies that produce sorbents have designed them to be relatively easy to apply and recover manually. Many sorbents come in pads or in long rolls that can be applied to beaches. Some sorbents can be re-used many times after wringing out the absorbed oil. Although these substances may be highly effective, they are expensive to use because of the initial cost of the sorbent and the high cost of labor to apply and collect them.

Commercial sorbents also have the advantage that special products can be applied to different spill situations. For example, some sorbents are highly effective on very thin slicks of oil. Other sorbents are more effective on highly viscous oils. Polyurethane foams have been fabricated with varying porosity to be selectively more effective on high viscosity oil or low viscosity oil.

In all cases the use of sorbents presents a new disposal problem. As a result, spill response specialists must carefully weigh the advantages of using sorbents because the problem of disposing of oil-soaked sorbents may be even more severe than the problem of disposing of recovered oil.

Evaluation of Sorbents

A great many sorbent materials are available commercially, so many, in fact, that a complete review of these materials would probably require an entire volume. Because of this, only a relatively few sorbents will be reviewed in this section. Those selected for evaluation are those that are well known, easily available, some that are known to be available in Alaska, and those for which independent test data is available. Table 33 shows sixteen sorbents that have been selected for evaluation in this section. This table describes these materials in considerable detail and rates them according to their expected performance effectiveness for various spill situations. The sorbents are rated according to their use: marine pickup (M); land pickup (L); and spill containment boom (B). This use is identified in the last column of Table 33 with the appropriate symbol. Some natural sorbents, indicated by (N), are also evaluated; however, the user must be cautioned that these sorbents are only economical if they are available locally, and if an easy means of disposal is available.

The sorbents are rated according to the criteria shown in Table 34. This rating is not intended to be absolute. That is, sorbents are rated for a particular application and, in addition, they are rated as they compare to sorbents of a similar material. For example, a natural sorbent may be rated highly as compared to other natural sorbents, but not necessarily highly as compared to much more expensive synthetically prepared sorbents.

Table 33 is a document that can stand alone since it provides both a description of each product and an evaluation. Some of the sorbents described on Table 33, however, have special characteristics or special problems, therefore some additional comments will be offered for several selected sorbents so that the reader can make better use of the product evaluation.

TABLE 33 SORBENTS EVALUATION

PRODUCT DESCRIPTION	PACKAGING	MANUFACTURER'S SPECIFICATIONS
SORBENT C Perlite and natural fibers (organic/inorganic) • Density 0.06 g/cc • Indefinite shelf life • Oleophilic and hydrophobic • Disposal by burning, burial, in asphalt; not biodegradable	• Loose material: 8.2 kg (.12 m^2) bags	• Absorbs 7 g oil/g sorbent • Easily deployed over large areas • Fast pickup rate • Recovery by vacuum or hand nets • Material is coherent in currents • Compatible with all skimmers and separators except belt and roller skimmers
FIBERPERL OR DICALITE High bulk material of inert perlite and cellulose fiber • Density of 0.07 g/cc • Indefinite shelf life • Oleophilic and hydrophobic • Disposal by burial; partially biodegradable	• Loose material: 8.2 kg (0.11 m^3) • Boom: jute fiber cloth enclosing sorbent in 3.1 m sections • Pillow: same as boom but in 0.6 m sections	• Absorbs about 6 g oil/g sorbent • Recovery by hand nets, boom sweeping, and vacuum pickup • Floats when saturated • Non-toxic to marine life • Pillows and booms interlock and tied together • Boom reinforced by 820 kg test line
OILSNARE Flat fibers of polypropylene • Ribbon Yarn (synthetic) • Density 0.05 g/cc • Indefinite shelf life • Melts at 150°C	• Bundles of yarn: 30 per 6.8 kg carton (approx. 0.6 x 0.4 x 0.5 m box)	• Spread by hand • Recovery by rakes or boat hooks • Disposal by burning or burial; can be squeezed and reused • Best used for final cleanup after skimming • Absorbs about 18 g oil/g sorbent (Alaskan crude at -19°C) = 17.1 l/kg • More effective on heavy oils
SLICKWIK Lighter fractions of corn cobs ground into granular form (completely organic) • Density 0.14 g/cc • Flammable • Absorbs water and sinks	• Loose material in 15 kg (.11 m^3) bags (weather proof polyethylene bags)	• Spread by hand or mechanical blower • Recovery by skimmer or fine mesh screen • Will not damage skimmers • Absorbs about 2 g oil/g sorbent • Effective on all oil thicknesses • Not recyclable; 100% decomposes when buried; biodegradable
GRABOIL Polyurethane foam treated for oleophilic and hydrophobic qualities (synthetic) • Density 0.02 g/cc • Indefinite shelf life • Susceptible to heat and flame	• Pad: 0.6 m x 0.3 m x 0.3 m • Boom: 0.2 m x 1.8 m x 15.3 m	• Deployed by hand • Recovered by hand or belt skimmer • Can be rolled & reused up to 20 times • Holds oil for up to 3 months • Disposal by burial or burning; not biodegradable • Absorbs 20 g oil/g sorbent • More effective on light oils
CONWEB SORBENTS Vegetable fiber treated for oleophilic, hydrophobic qualities; reinforced with netting (modified organic) • Density 0.05 g/cc • Flash point 205°C • Unlimited shelf life when in container	• Blankets: 0.9 m x 61 m x 0.6 cm • Pad: 0.44 m x 0.44 m x 0.6 cm • Sweep: 0.44 m x 0.44 m x 0.6 cm • Strips: 0.08 m x 0.66 m x 0.6 cm • Boom: 2.4 m length x .25 m dia.	• Deployed by hand • Recovered manually • Reusable 3 to 10 times • Disposal by burning or burial; partially biodegradable • Absorbs 16-20 g oil/g sorbent quickly • Boom sections have spring loaded interlocking system; can be towed <2 knots • Boom reinforced with 1100 kg test line • More effective on heavy oils
PETROTRAP Polyurethane foam treated for oleophilic and hydrophobic qualities	• Foam Sheets: 63.5 cm x 33.0 cm x 1.5 cm • Booms: Same size covered with fiberglass membrane	• Deployed by hand for marine spills • Manual recovery • Booms used in conjunction with skimmers or oil herders • Disposal by incineration; not biodegradable • Reusable after squeezing • Absorbs 8 g oil/g sorbent

TABLE 33 SORBENTS EVALUATION (CONT)

INDEPENDENT TEST RESULTS BASED ON (1) ENV. CANADA (2) MOPS (3) OSIR	EVALUATION FOR REMOTE ARCTIC ENVIRONMENTS	SORBENT RATING
• Not reusable • Medium pickup 6-17 g oil/g sorbent with high % water • Increasingly effective on heavier oils • Effective on thin slicks 2-5 g/g (50-80% water) • Successfully used in the field on heavy oils (1,3)	Advantages • Successful in field application Disadvantages • Not reusable • High water pickup	○ L ⊗ M Found to be generally not reusable
• Absorption 3-3.5 g/g with high % water • Relatively high cost • Dusty, may irritate eyes • May clog equipment in loose form • Boom deteriorates, connectors poor, leak oil (2,3)	Disadvantages • Pillows and booms difficult to connect in cold weather • Clogs equipment • Boom design tested unsuccessfully • High water pickup	⊗ L ⊗ M Difficult to use; poor field application
• Not reusable • Low absorption 1-2 g/g with high % water • Good on thin slicks absorbing 2-4 g/g with 20% water • Performance not viscosity dependent • Successful field use on heavy oils (1,3)	Advantages • Excellent on thin slicks • Successful in field use Disadvantages • Not reusable • Low absorption	○ L ○ M Generally not reusable
• Not reusable • Low absorption 5 g/g with no water • Performance better on heavy oils • Poor on thin slicks (1)	Advantage • Good on heavy oils Disadvantage • Not reusable • Low absorption • Poor on thin slicks	○ N Generally not reusable
• Highly reusable with wringer • Absorbs 30-50 g/g with no water • Absorbs 1-5 g/g on thin slicks with 50% water • Performance best on thick oils but excellent on light oil • Poor oil retention qualities • Shown effective in field testing • Special incineration for disposal to avoid toxic vapor during burning (1,2)	Advantage • Highly reusable • High absorption • Excellent on all oils • Economical Disadvantage • Poor retention qualities • Toxic vapor when burned	○ M Highest absorbency non-wetting properties, reusable; has disposal problems
• Highly reusable with wringer • Good absorption 17-25 g/g with water content increasing with heavy oils • Absorbs 3-4 g/g on thin slicks (20% water) • Deteriorates with rough handling • Booms saturate easily with water • Economical price • Field use on diesel and crude spills; more effective on diesel (1,2)	Advantage • Highly reusable • Economical • Good absorption • Field tested well on light oils Disadvantages • Deteriorates when roughly handled • Boom saturates easily • Field performance poor on crude oil	◐ L Convenient forms for various uses, good absorption rates, reusable
• Very slow pickup rate • High absorbency 45 g/g with 50% water • Requires special incineration to avoid toxic vapors	Advantages • High absorption Disadvantages • Slow pickup rate • High water pickup • Toxic vapors when burned	○ M Not among top sorbents but is qualified for use if available

(CONTINUED)

TABLE 33 SORBENTS EVALUATION (CONT)

PRODUCT DESCRIPTION	PACKAGING	MANUFACTURER'S SPECIFICATIONS
SPILL CONTROL CHALLENGER SORBENTS Specially treated polyurethane sorbent (synthetic) • Density 0.03 g/cc • Flash point 115°C • Indefinite shelf life • Packaged in vacuum-sealed containers	• Booms: 1.8 m x 0.2 dia. with snap connector • Pads: Type FPD: very low density, for water surface spills Type PEP: for light viscosity marine spills Type SPD: land spill pad • Strips: 0.4 m x 1 cm x 1.5 cm • Pillow: 5 gallon capacity • Sweeper: fluff for high viscosity oil in .12 m^3 bags	• Deployed and recovered manually • Disposal by burning or burying • Boom netting is high strength nylon • Absorbs some water but oil displaces the water • Reusability indefinite with wringer • Absorbs up to 60 g oil/g sorbent • Better on heavy oils
SORB-OIL Hydrophobic oleophilic sorbent made from wood fibers • Use below 66°C • Biodegradable	• Booms: 6.1 meter sections x 0.2 m diameter • Chips: small random pieces in 20 kg and 9 kg cartons • Swabs: 0.5 m x 0.2 m enclosed in nylon mesh • Mats: 0.6 m x 0.7 m x 1/2 cm • Fluff: Smaller pieces of chips	• Deployed manually • Recovery by rake or boat hook • Absorbs up to 22 g oil/g sorbent • Loses hydrophobicity when handled roughly • Boom enclosed by nylon mesh reinforced by 0.5 cm rope (also used for connecting boom sections • Chips for use on heavy oils • Disposal by burning or burial
3 M SORBENTS Microfibrous synthetic polymeric fiber • Density 0.06 g/cc • Not biodegradable • Indefinite shelf life	• Rolls: 46 m x 0.9 m for small spills in open area • Sweep: 30 m x 0.6 m for thin slicks • Sheets: 0.5 or 1.0 m sqs. for confined area • Particulate: 11.5 kg bags for large spills • Pillows: mesh bags .4 m x 0.7 m for large concentrated oil pools • Booms: 2.5 m long x .3 m dia.	• Absorbs up to 22 g oil/g sorbent • Fast pickup rates • Manual deployment; particulate by blower • Recovery manual, boat hook • Booms reinforced with rope • Reusable up to 30 times • Disposable by burning with no ash; buried; or dissolved at 135°C for use as low grade oil
PEAT MOSS Organic Fiber • Density .08-.17 g/cc depending on particle size and moisture content • Must be kept dry	• Bags: size depends on distributor	• Will absorb 8-12 g oil/g sorbent • Manual deployment or by blower • Can be disked into loose soil or raked • Disposal by burial or incineration • Not reusable
STRAW Local Distributor • Natural fiber (organic) • Density <.99 g/cc • Subject to microbial attack • Burns easily • Store away from moisture and heat	• Bales: 25-50 kg	• Sinks easily • Not reusable • Absorbs 4-6 g oil/g sorbent • Deploy by hand, mulcher, blower • Recover by hand, net skimmer • Disposal by burial or burning
J & L POM POM Synthetic straw material treated for oleophilic and hydrophobic qualities	• Bundles of straw-like synthetic, 30 Pom Poms per 7 kg box	• Manual deployment • Recovery by hand or boat hook • Disposal by incineration or land fill • May clog skimmers • Absorbency 40 g oil/g sorbent • Recommended for heavy, viscous oils
GLASORB Fiberglass insulation type material treated for oleophilic and hydrophobic properties; strengthened by netting	• Comes in rolls 2.5 cm x 0.6 m x 22.8 m	• Manual deployment and recovery • Disposal by burning with low ash; not biodegradable

TABLE 33 SORBENTS EVALUATION (CONT)

INDEPENDENT TEST RESULTS BASED ON (1) ENV. CANADA (2) MOPS (3) OSIR	EVALUATION FOR REMOTE ARCTIC ENVIRONMENTS	SORBENT RATING
• Highly reusable • Type PEP significantly most effective, absorbs 25-47 g/g with oil water • Absorbs 3-4 g/g thin slicks (60-80% water) • Better on heavier oils • Field use on crude spills (1,3)	Advantages • Reusable • High absorption • Good thin slick absorbency • Good on heavy oils • Field tested on crude oil Disadvantages • Disposal not evaluated in tests, but vapors from burning could be toxic	◑B Reusable with high absorbency ●M High absorbency and non-wetting properties, reusable and easily disposed ●L High absorbency, reusable, easy disposal, available in many forms
• Low absorption 6-7 g/g with 20% water • Excellent boom design with good connectors which are easily manipulated and do not leak • Easily incinerated or biodegradable • Used in offshore arctic diesel fuel spill (2,3)	Advantages • Excellent boom • Easily incinerated • Arctic tested • Economical Disadvantages • Low absorbency	●B Excellent field tested boom; high containment ability
• Highly reusable with wringer • 12-18 g/g absorbency with little water • Poor on thin slicks 0.3 g/g • Performance not viscosity dependent • Easily incinerated • Very good pads, rolls or sweeps • Used in the field extensively on all types of oils on land and marine spills (1,2,3)	Advantages • Moderately high price • Good absorption • Easily burned or melted • Extensively proven in the field • Highly reusable Disadvantages • Poor on thin slicks	○B Field proven boom ◑M Good absorbency, non-wetting properties, reusable, easily disposed ○L Available in convenient forms, good absorbency, reusable
• Not reusable • Absorbs some water • Oil absorption 3-4 g/g • Absorption 2-3 g/g on thin slicks (70-90% water) • Better on thick oils but will sink if too heavy • Locally available • Used for combustion promoter • Ineffective with >35% water content	Advantages • Locally available • Inexpensive Disadvantages • Difficult to recover • Low absorbency • Not reusable • Difficult recovery	●N Good inexpensive natural sorbent with relatively low non-wetting properties for natural sorbents
• Not reusable • Absorbs 2-3 g/g oil with high water content • Better on thin slicks, 3-4 g/g (30-50% water) • Performance not viscosity dependent • Used successfully on many types of oil spills • Very economical (1,3)	Advantages • Locally available • Inexpensive Disadvantages • Difficult to recover • Low absorbency • High water absorbency • Not reusable • Difficult recovery	○N Very inexpensive; absorbs water easily
• Used successfully on marine spills of crude oil	Advantages • Used in field work • High absorbency • Reusable Disadvantages • Lack of documented testing	⊗ Unproven in formal testing except by manufacturer
• Absorbency 40-56 g/g with 35% water • Absorbs quickly, drains rapidly when lifted from oil • Not field tested • Gloves must be used to avoid fiberglass splinters (2)	Advantages • Low price • High absorbency Disadvantages • High water pickup • Low retention after lifting from oil • Hazardous to handle	○ Could be applicable because of good sorbent properties; unavailable in convenient forms for use; hazardous to handle

●Above Average	M-Marine Pickup
◑Average	L-Land Pickup
○Below Average	B-Containment Boom
⊗Not Suitable For Indicated Application	N-Natural Sorbent

TABLE 34 CRITERIA FOR EVALUATING SORBENTS

Marine Use	Land Use	Sorbent Containment Boom
Absorbency in All Types of Oils and Slick Thicknesses	Absorbency in All Types of Oils and Layer Thicknesses	Field Proven Capabilities
Non-Wetting Properties	Reusability (Economy)	Containment Abilities
Reusability (Economy)	Proven (Arctic) Field Use	Ease of Deployment--Connector Design
Proven (Arctic) Field Use	Convenient Sorbent Forms	Non-Wetting Properties
Convenient Sorbent Forms	Disposal Methods	Reusability (Boom Life)
Disposal Methods	Ease of Recovery	Absorbency
Ease of Recovery	Ease of Disposal	Disposal Methods
Ease of Deployment		

Graboil is an example of an effective sorbent that has a special problem. Graboil has a high absorption rate while retaining very little water; however, it is given a low rating because it gives off toxic vapors during disposal by burning. If this sorbent is used in an area where disposal is not a problem, or when disposal by burning is not planned, Graboil would be given a much higher rating. Petrotrap is a similar product that has high absorbency, but also has a problem if disposal by burning is planned.

A product developed by Spill Control Challenger Sorbents was found to be effective, however, its behavior during disposal by burning has not been noted, so it may also have a problem with toxic vapors.

The product Sorb-Oil does not have nearly the sorbent capacity as some of the synthetic materials, but it is rated highly because it has been developed to an effective sorbent boom.

3M Sorbent products are widely used and offered in convenient sizes and shapes for a variety of applications. They are durable, reusable, and can be incinerated without producing toxic vapors. Because of these good qualities, 3M sorbents are rated highly even though their sorbent capacity is not as high as some other products.

Peat Moss is rated highly as a natural sorbent even though its sorbent capacity is not high compared to synthetic materials and it absorbs a high percentage of water. If peat moss is available, it would be effective for use on land where recovery is easy. It would not be nearly as effective on water because it might sink or it could be lost in waves or currents before it is recovered.

Glasorb is an effective sorbent material but it is not recommended for use because of the hazards of application and recovery.

This discussion should indicate to the reader that there are no fixed rules for evaluating sorbents. The evaluation provided on Table 33 should be helpful; however, each sorbent must be evaluated separately for the intended application since the best product to use is likely to be determined by the spill situation.

TRANSFER SYSTEMS

Spill response transfer systems are used to move oil collected by recovery devices into tanks for temporary storage or to move the recovered product directly to on-site disposal systems. In a severe arctic environment, the oil to be transferred may contain ice and other debris. In addition, it may have a very low temperature that results in an extremely high viscosity. Thus, the characteristics of the recovered product and the environment in which it is collected require that a highly specialized system for transferring recovered oil be used, with each part of the system specifically designed for cold weather operations.

The scenarios developed for this study place varying requirements on oil spill transfer systems. The pipeline spill, the fuel farm spill, and the tank truck spill are least demanding in requirements for a transfer system. These spill situations occur at breakup or in early summer; therefore the standard transfer systems generally used with the spill recovery devices could be expected to be satisfactory. The pipeline spill is perhaps more severe than the other two in that it may involve oil mixed with some ice, there could be relatively cold ambient air temperatures, and a fairly large amount of product may be recovered. Even in this situation, however, conventional transfer systems are likely to be adequate.

The oil well blowout is the most severe spill situation in terms of the amount of product to be recovered and the environment in which the spill response effort must be undertaken. The blowout scenario is set in severe winter weather conditions with low air temperatures causing the spilled product to become highly viscous a short time after it strikes the ground. In addition, the spilled oil mixes with the ice and snow on the surrounding frozen tundra. Only a specially developed arctic transfer system could be expected to be effective operating in this environment. The comments and requirements developed for an arctic spill transfer system are primarily directed to the special problems that occur in the oil well blowout scenario.

The paragraphs that follow briefly describe the elements of the transfer system and the special problems each system may have in a cold weather environment. These elements consist of a prime mover, a pump, a hose, and a fluid to be moved.

Prime Mover

The prime mover is the power package necessary to operate the other system components. This element of the system is generally a gasoline engine, a diesel engine, or gas turbine. High pressure air can also be used to power a pump, but in arctic conditions this is considered a less desirable source of power because of the problems of moisture in the air freezing in the system. Things to look for in selecting a prime mover that will be reliable for cold weather operations include the following:

- Adequate power for system operation
- Ability to start in extremely cold temperatures
- Gaskets, seals, and belts that hold up in low temperatures
- Hydraulic fluids that flow adequately at low temperatures
- Engines that are safe for use near the volatile products of a spill.

Pump

Satisfactory operation at low temperatures is the primary requirement for the pump, however a number of other special characteristics must also be considered.

Portability--

The pump must be air-transportable in light aircraft and light enough to be carried by two or three men over rough terrain.

Cold-Weather Performance--

The pump should be able to operate at low air temperatures without shelter in exposed locations. Personnel wearing arctic clothing should be able to operate controls and make minor adjustments easily.

Durability--

The pump should be able to operate for long periods of time with little or no maintenance. Field maintenance should not require special skills or tools.

Performance--

The pump should be able to maintain a minimum specified flow rate. This rate is likely to be determined by the capability of the recovery devices that will be used with it, however a nominal flow rate in the range of 100 to 300 liters per minute may be considered as an approximate goal.

Emulsification--

Since the recovered product will probably require oil/water separation, keeping emulsification levels low is desirable. Generally positive displacement pumps have lower levels of emulsification than centrifugal pumps.

Tolerance of Debris--

Pumps used in the Arctic should be capable of passing stones, debris, and chunks of ice having a diameter of up to about 2 cm.

Viscous Oil--

Pumps should be capable of handling a recovered product with viscosity of up to 1500 centistokes.

Suction and Lift--

These characteristics depend on the intended application, however a static suction head and discharge head of about 3 m may be considered normal.

Self-Priming--

Pumps should be self-priming because of problems of surges in the lines, possible freezing in the lines, or clogging of debris strainers.

Hose

Normal pump discharge hoses may become brittle and crack at temperatures substantially below freezing so special low temperature hoses and seals must be used. In addition, the fluid may freeze and clog in long lengths of hose, therefore the hose must be well insulated and may even require heating.

Fluid

The fluid to be moved is basically oil carrying some water, debris, and ice. Large pieces of ice and debris can be rejected at the pump intake; however, the pump must be able to handle some smaller ice chunks. Some positive displacement pumps can pass solids with diameters in the range of 2 to 7 cm.

High viscosity fluids can be handled in a number of ways. First, the system should use a pump specially designed to pass highly viscous fluids. Second, the viscosity of the fluid can sometimes be reduced by heating, stirring, or mixing the fluid near the pump intake.

Transfer Requirements

For the oil well blowout scenario, the transfer system must have the characteristics described in the preceding paragraphs for an arctic transfer system. The requirement is for a rugged, low temperature system capable of pumping a highly viscous product that may be mixed with ice, snow, and some debris.

For the other spill scenarios, the transfer system must have some capacity for passing debris and the pump must have a reasonable rate of flow; however, most normal systems that would be used with the recovery system would be adequate.

Evaluation of Transfer Systems

Table 35 shows some of the pumps that were screened for possible use in an arctic transfer system in a recent study performed for the Canadian Arctic Marine Oilspill Program (AMOP) (73). Table 35 shows the characteristics of a number of types of positive displacement pumps since these are, as a class, the most suitable for this application. Of the pumps shown, the Moyno progressive cavity pump and the Offshore Devices double-diaphragm pumps were tested under rigorous simulated arctic conditions. Both of these pumps performed well in the tests and were found to be suitable for use as part of

TABLE 35 POSITIVE DISPLACEMENT PUMPS EVALUATED

NAME	PRINCIPLE	MAXIMUM DISCHARGE CAPACITY (l/min)	PUMP SPEED (rpm)	SOLIDS CAPACITY (cm)	APPROX. WEIGHT (kg)	REMARKS
Dorr Oliver (ODS-4)	Single-acting diaphragm	340	15	10.2	275	Freezing problems with air supply; heavy
Gorman-Rupp (4DX-3)	Single-acting diaphragm	375	52	7.6	185	Not suitable for viscosities greater than 80 cSt
Homelite (11.D03.1)	Single-acting diaphragm	260		7.6	50	Low pumping capacity
LFE Midland (33E-4028)	Single-acting diaphragm	290		7.6	133	Suitable but double-acting diaphragm pump preferred
M.D. Lobeline (4540L)	Rotating lobes	1100	750	4.7	90	Not self-priming
Megator (L300)	Triplex reciprocating	340	570	0.6		Low solids capacity
Moyno (ISWG10H)	Progressive cavity	795	750	2.0	225	Suitable - 1L10H model tested in cold conditions
Offshore Devices	Double-acting diaphragm	1325	60	7.6	70	Suitable-pump tested in cold conditions
Spate (Four Inch)	Oscillating impeller	885		1.2	410	Low solids capacity; high emulsification
Warren-Rupp (SA3-A)	Double-acting diaphragm	1060	170	7.6	110	Freezing problems with air supply
Willden	Double-acting diaphragm	640		1.0	55	Low solids capacity; air freezing problems

an arctic spill response system. The principal features of each of these pumps are described in the paragraphs that follow.

Offshore Devices--

This pump was specifically designed for use in a spill response system. The pump was designed to pass an oil/water/debris mixture, which it does very well, passing chunks up to 7.6 cm (3 inches) in diameter. The pump suffered a casing crack during the tests, but this was patched and the unit continued to perform well. As an endurance test, the pump was run continuously for a period of 96 hours at temperatures between +5°C and -10°C. To improve performance, the pump needs a heavier casing and it should be equipped with a drain plug for use in cold climates. At 70 kg, the pump is much lighter than the 225 kg Moyno pump, and therefore is recommended when weight is a primary consideration.

Moyno--

This progressive cavity pump was able to pass chunks of ice with dimensions of 5x2.5x1.9 cm. Although the manufacturer cautions that the pump should not be run dry, it was run dry in the tests for periods of 15 and 20 minutes with no adverse effects. In an endurance test, the Moyno pump was run continuously for 96 hours at temperatures down to -17°C pumping oil with a viscosity of up to 500 centistokes. Although the pump is much heavier than the Offshore Devices pump, its shape made it easy to handle. The pump would be more suitable for use in a transfer system if it were lighter and if it had a central drain plug. The progressive cavity pump also has the advantage of producing a steadier flow than the double diaphragm pump. This pump was not designed for use in a recovered oil transfer system, but it has been widely used in industry and is likely to operate effectively in a transfer system.

STORAGE

Temporary storage may be required after spilled oil has been recovered. The recovered oil may be stored awaiting transfer to another location, on-site disposal, or waiting to be converted to some secondary use such as road oiling for dust control. Likely methods of storage that could be applied for the inland spill scenarios considered in this study include:

- Reserve pits
- Permanent storage tanks
- Tank trucks
- Vacuum trucks
- Oil drums
- Portable storage containers.

Reserve pits, permanent storage tanks, and various kinds of tank trucks could be used as they are available. In many remote, inland locations, these permanent storage facilities would not be available. In these areas portable storage containers would be most useful. These containers are readily available at many remote locations in Alaska, such as pipeline pumping stations. Portable containers are also available from oil spill cleanup contractors and may be found in some villages. The advantages of these portable storage containers is that they can be easily transported to remote inland locations and they require a low volume storage space when they are not in use.

Storage Requirements

The oil spill situations considered in this study all require some form of temporary storage for recovered oil that is awaiting on-site disposal or transport to another location. The type of storage that may be employed varies with the spill scenarios. The oil well blowout scenario will employ an existing pit for storage plus the use of fixed tanks that may be available or tank trucks. The pipeline spill scenario may employ vacuum trucks for temporary storage and transport in areas where recovery sites are accessible to these vehicles. Because of the remoteness of most of the recovery sites, however, the use of portable storage containers is likely to predominate. The recovered refined product collected from the fuel farm spill at McGrath is likely to be cleaned and used. Storage, therefore, may be in permanent tanks, or in some cases, portable storage containers. Since the tank truck spill occurred along the haul road, vacuum trucks will probably provide the principal mode of storage and transport. Some portable containers may also be required in more remote locations away from the road.

Evaluation of Storage Systems

Petroleum tank trucks that could be used for temporary storage of recovered oil hold up to 64,000 liters (17,000 gallons). Vacuum trucks used to recover the spilled product and for temporary storage typically have a capacity of 3,800 to 17,000 liters.

Portable storage containers are produced by many manufacturers and come in a range of sizes to meet nearly every use. Table 36 shows some of the containers available arranged according to manufacturer, and includes a rating of their expected performance in remote, arctic locations.

DISPOSAL

The lack of adequate disposal methods for recovered oil remains one of the major problems of the spill response effort in remote inland areas of Alaska. In most cases disposal facilities are simply not available. If disposal sites can be identified, the problem of transporting the recovered product to these sites may be tremendously difficult, prohibitively expensive, or both.

Salvage is the most desirable disposal method when this alternative is possible. Salvage techniques include injection of the recovered product into the pipeline, direct reclaiming, refining the oil, reinjection into the well, or injection into a salvage well. The feasibility of these alternatives depends on the condition of the recovered oil, logistics problems, and the availability of the necessary equipment. Unfortunately, even when

TABLE 36 PORTABLE STORAGE CONTAINER EVALUATION

MANUFACTURER	CONTAINER	DESCRIPTION	WEIGHT (kg)	VOLUME (liters)	MIN. TEMP. (°C)	COMMENTS RELATED TO EMPLOYMENT
B. F. Goodrich 430 S. Main St. Cohasset, Mass. 02025	Storitainers	High strength ends and fabrics coated with special rubber compounds	20 to 617	450 to 90,000		Made only for stationary storage Tanks manufactured according to storage requirements
B. F. Boodrich 430 S. Main St. Cohasset, Mass. 02025	Mov-a-tainers	Designed to be transported when full, therefore constructed of extremely high strength material	--	up to 19,900	--	Appear to be better suited for cold region use than Storitainers because of added strength and special capability to be moved when full.
Goodyear Tire and Rubber Co. Industrial Products Div. Akron, Ohio 44316	Pillow Tank	High strength fabric coated with rubber provides high strengths at low temperatures	--	3,790 to 246,000	-40°	Largest capacity tank expands from 0.6 m x 1.1 m x 4.0 m when stored to 1.8 m x 6.9 m x 24 m when full.
Kepner Plastics 4221 Spencer St. Torrance, CA 90503	Portable Storage Tank	Elastomeric coated nylon fabric	45 to 280	1,140 to 1,890	--	Not tested in cold weather.
Firestone Coated Fabrics Co. 2525 Firestone Blvd. P.O. Box 1592 Southgate, CA 92080	Fabritank	Two-ply construction using nitrile rubber coatings	227 to 1,136	18,900 to 189,300	-57°	In use in the Arctic since 1961; suitable for cold regions application.
Uniroyal Engineered System Dept. Mushawaka, Indiana 46544	Static Storage Tank	Single-ply nylon fabric coated on both sides with polyurethane.	11 to 684	950 to 378,500	-51°	Used in the Arctic for storage; suitable for use in cold regions.
Dunlop Rubber Co., Ltd. Cambridge Street Manchester 1, England	Collapsible Containers	Double-ply fabric inside is coated with natural or synthetic rubber. Outside is polychloroprene.	--	230 to 227,000	--	Used in the Antarctic; suitable for use in cold regions.

the recovered product is clean enough to salvage, the problems of transporting the oil to a location where salvage can occur may far exceed the value of the reclaimed product. In most cases some form of on-site disposal is likely to be the most effective disposal alternative in remote inland locations.

In northern latitudes the disposal problem is further complicated by the fact that many of the secondary uses for recovered product used in southern latitudes are not possible in arctic and subarctic situations. For example, in lower latitudes recovered oil is used for lower grade products such as asphalt, road oiling, dust control, and weed control. Burial and land spreading are methods of disposal that are successfully practiced in southern sections of the United States. In the south, recovered oil can be spread on land and completely degraded in less than a year. In the far north, biodegradation progresses much more slowly, and oil spread on land may cause extremely adverse problems with permafrost, soil erosion, and damage to vegetative cover. The problems of transport to a disposal site and possible environmental damage resulting from secondary uses of recovered product make some form of on-site disposal an attractive alternative when this course of action is possible.

Some methods of treating the spilled product, either on the water or on the ground, amount to a method of disposal that occurs without the intervention of the recovery step. As a result, this study will consider the disposal problem in two steps; disposal without recovery and disposal of the recovered oil.

Disposal Without Recovery

Techniques for disposal without recovery include actions that can be taken when mechanical recovery is not possible, or actions that can be taken more quickly than mechanical recovery to minimize the impact of an immediate threat to the ecology. The methods of disposal without recovery considered in this section include *in situ* burning, biodegradation, and the use of surface collecting agents and dispersants.

In Situ Burning--

The idea of disposal by *in situ* burning has become popular, particularly for remote offshore arctic regions where spilled oil may be pooled between pieces of ice and most means of mechanical recovery are not likely to be effective. Because these areas may be inaccessible to any other method of spill response, *in situ* burning seems attractive; however, even in these areas there is some concern for the fate and effects of the residue of burning. *In situ* burning in remote inland areas presents many more problems. When burning occurs inland, there is concern for damage to permafrost and vegetation in addition to the fate and effects of the residue of burning.

In situ burning has been used in specific cases as a method of disposal in inland Alaska with the approval of the Alaska Department of Environmental Conservation (ADEC), and apparently with no long-lasting adverse effects. Crude oil recovered after the Trans-Alaska Pipeline spill near Fairbanks in February 1978 was first trucked to Valdez for salvage. When spring truck weight limitations went into effect in mid-April, ADEC gave permission for a controlled burn.

Contaminated vegetation and oil were pushed away from the pipeline and a small fire break berm was built to provide a buffer between the pipeline and the area to be burned (74). About 80,000 liters (500 barrels) of the spilled crude oil were collected in this area for burning. The entire area burned for a period of about two hours. Later, oil that remained in isolated spots was burned for a period of about one week.

The oil burned easily on the water surface. As the water was heated from burning, globs of oil rose from the ground through the water column igniting with small explosions as they broke the surface. The burning pond had water depths ranging from a few centimeters to about one meter.

Some of the oil was burned off ice. Burning occurred rapidly with the heat rising so only minor melting occurred. When burning occurred on frozen tundra, the thaw went to a depth of several centimeters. Later in the summer the sheen that remained on the water surface was gathered with a surface collecting agent and recovered with a mechanical skimmer.

In situ burning appears to have been a successful method of disposal after the Fairbanks spill; however, in some inland areas burning may be far more damaging than allowing the residuals from the recovery process to degrade naturally. Even at Fairbanks, *in situ* burning probably would not have been required if a more satisfactory method of on-site disposal had been available. For example, the burn at Fairbanks consisted principally of relatively clean product on water. If a small open flame burner had been available, the crude oil could have been recovered from the water and burned quickly with a clean flame. The oiled vegetation may also have been removed and burned in a portable open pit burner and no permafrost melting would have occurred. Of course, the decision to remove the oiled tundra would have to be weighed carefully to be sure that the recovery and disposal procedures were not more harmful than leaving the spilled product to degrade in place.

Biodegradation--

The biodegradation of petroleum products exposed to the atmosphere is a process that occurs naturally; however, over the last few years several products have been developed to selectively enhance the biodegradation of petroleum products. At this writing EPA has accepted six bacteriological agents for use in cleaning up oil spills. Most of these agents are designed for use on sea water and are most effective on a very thin slick in warm water and air conditions. Although most of the agents are designed for use on water, advertising stresses that they continue to remain active even after the oil has washed ashore. Recently EPA accepted two bacteriological agents developed by Polybac, Inc. of Allentown, Pennsylvania (75). One of these products is designed for use on sea water and one is designed for use on fresh water. The product designed for fresh water use may provide a spill response alternative for inland rivers, lakes, and wetlands providing it can be shown to be effective in these areas and there are no adverse environmental impacts resulting from its use. In considering this product, or similar products, for use in inland areas of Alaska, there must also be concern that the product is effective in areas with low air and water temperatures. There have been a number of ongoing projects studying the biodegradation of petroleum products spilled on the ground and the effect of these spills on local vegetation. Similar studies should be performed to test the effectiveness of bacteriological agents in these conditions. The idea of applying an agent to enhance the bacteriological degradation of spilled products is an attractive spill response option; however, this option could not be recommended until existing agents have been evaluated in the field.

Surface Collecting Agents--

Surface collecting agents are chemicals that are applied along the edge of a spill. Here they form a layer on the surface of the water that prevents the further spreading of oil and compresses thin films of oil into thicker layers. Surface collecting with a chemical is not a complete disposal method in itself, but only the first step used to concentrate the spill so that recovery or disposal methods will be more effective. The basic requirement of the collecting agent is that its spreading pressure be greater than that of the spilled oil. Two commercial surface collecting agents are currently in common use, Shell's OIL HERDER and EXXON's COREXIT OC-5 OIL COLLECTOR.

The Shell OIL HERDER is a water insoluble surface active agent that limits and concentrates an oil spill. OIL HERDER has a flash point of 78°C and a pour point of 2°C. Although it has been successfully applied at temperatures down to -4°C by keeping the solution agitated, it is recommended that the product be stored at temperatures of 27°C. This product can be applied at any ambient temperature as long as the product itself is kept above its pour point; however, the high pour point would appear to severely limit its applicability in arctic regions.

EXXON's COREXIT OC-5 is a surface collecting agent with a flash point of 85°C and a pour point of -29°C. COREXIT OC-5 was used successfully to collect the light sheen that remained after burning in the Fairbanks pipeline spill (74).

Surface collecting agents are not useful in fast moving streams. For purposes of this study, then, surface collecting agents may be useful in collecting a sheen that remains on inland lakes or wet areas after thaw in the blowout scenario. They may also be useful in collecting a thin slick in still water areas after the tank truck spill. Collecting agents are not likely to be useful in either the pipeline spill or the fuel farm spill.

Dispersants--

Nearly all dispersants are designed for use in salt water. Their effectiveness in this application is predicated on their ability to diffuse the spilled product in a deep column of water and to become widely diffused by currents and wave action in a large volume of the ocean. Although some dispersants can be used in fresh water, the volume of water necessary for effective dispersion is generally not available in inland situations.

Some recent laboratory tests suggest that dispersants could be used to clean oiled beaches. These tests found that the application of dispersant changes the nature of the contamination from one of large drops of oil that physically adhere to the shore, or may be buried, to small drops of oil that penetrate the sand but may be filtered out by the action of the water moving through the sand (76). The idea here is that the smaller, dispersed droplets show less adhesion to the sand and are more likely to be cleaned out by the action of the waves than the large droplets. The dispersed oil does penetrate deeper into the sand, but the study postulates it is still more likely to be cleaned away.

These laboratory tests and extrapolations to field situations deserve serious consideration; however, additional tests and studies should be made before recommending dispersants for cleaning beaches. First, the possible impact of the oil and dispersant penetrating deeper into the sand must be examined. In some cases deeper penetration may be more adverse than leaving larger lumps of oil on the surface. In addition, the ability of various kinds of wave energy to wash the dispersed products out of different types of beach soils should be investigated. The use of dispersants appears to be an innovative approach to cleaning beach spills, but some significant technical questions must be answered before this procedure can be recommended.

Disposal of Recovered Oil

Salvage--

Savlage is a desirable disposal technique when local conditions permit this alternative to be used. Salvage is the most "conservative" method of disposal both in terms of preservation of resources and environmental conditions; however, salvage may sometimes not be possible either economically or physically.

Salvage techniques include injection of the recovered product into the pipeline, direct reclaiming, refining the recovered oil, or injection into a storage well. The feasibility of these alternatives depends on the condition of the recovered oil, the logistics problems, and the availability of the necessary equipment.

Direct reclaiming is also an important salvage alternative. A refined product that has been recovered soon after it has been spilled, or a product that has been isolated from severe contamination, may be returned to be used for its original purpose with only a small amount of filtering, water separation, or cleaning. Diesel fuel and lubricating oil can probably be reclaimed if they do not change in composition during the period of their exposure. Number 2 heating fuel could also be returned to its original use with some filtering and water separation. The refinery at North Pole could probably reclaim recovered crude providing transportation can be found from the spill site.

Incineration--

When salvage is not possible, incineration of the recovered spill is often the next most desirable method of disposal. In order to be an acceptable method of disposal, incineration must occur without excessive levels of smoke or leave residues of burning that themselves become a major disposal problem. Incineration has sometimes been avoided in the past because of the problems of smoke and residues; however, a number of incineration devices are currently available that both burn clean and leave only a small amount of residue from combustion. This study will briefly review the characteristics of open flame burners, open pit burners, and rotary kiln burners.

Table 37 shows examples of incineration devices that could be used to dispose of recovered oil. The first three devices shown are open flame or flaring burners. These burners were designed to rapidly burn off crude oil during an offshore well test. These burners have the capacity for burning oil at a tremendous rate, up to 1893 liters per minute (500 gallons), with a clean, smokeless flame. They are designed to burn an oil/water/mud mixture that may contain small rocks up to 6 mm in diameter and as much as 40% water. Because of those characteristics, these burners are ideally suited for disposing of recovered oil. The big problem with flaring burners is that they were designed for use on offshore drilling platforms. They are large, heavy, not portable, and not generally suitable for remote inland areas of Alaska. Since the concept is so well suited to the disposal of recovered oil, there is a need to design a smaller, easily transportable flaring burner to dispose of remote inland spills.

Table 37 next shows three models of open pit burners used for disposing of oiled debris, large chunks of highly viscous oil, or even the residues of *in situ* burning. Open pit burners have often been shunned for disposing of oiled debris because the burning has been accompanied by large volumes of black smoke and airborne particulates. The open pit burners shown here represent a considerable improvement over some of the older burners. These devices have added large volumes of high velocity air both over the fire and sometimes under the fire with the result that the discharge of smoke is relatively low, generally well within the limits of regulatory agencies. The portable burner produced by TRECAN is a new development designed for oil spill cleanup in remote arctic areas. The performance of this burner has been confirmed by cold weather field tests. This burner is smaller and more portable than most other open pit burners, but it may still be too large and heavy for some remote inland areas of Alaska. Figure 47 provides a sketch of this burner.

In addition to the burners shown on this chart, rotary-kiln burners would be useful in cleaning the oiled sand of river banks or oiled soil. Unfortunately, most of these devices are large and heavy, generally too large for use in remote inland areas. The concept of the rotary-kiln burner as a beach cleaner is good; however, what is required is a small, portable device that could easily be transported and used in remote locations.

The use of rotary-kiln burners to clean oiled sand pre-supposes that the oiled sand can be efficiently collected for cleaning. Three prototype mechanical devices for collecting oiled sand have been developed and tested in the laboratory (77). One device is a spined wheel device that picks up

TABLE 37 INCINERATION DEVICES FOR DISPOSAL OF RECOVERED OIL

MANUFACTURER	BURNER	DESCRIPTION	CAPACITY	WEIGHT	COMMENTS
National Airoil Burner (Dist. by Otis Engineering)	NOA Model CB-12	Clean burning unit using water injection to avoid hydrocarbon fallout; open flame device consisting of dual cans and 3 variable flow nozzles for gas flow control to atomizers	1.7 to 80 m^3/hr oil and debris	535 kg	Has separators to process oil/water mixture or mud, drilling compounds and small (6 mm) rocks; can be air transported and boom mounted
Noralco Overseas, Inc.	Noralco Dual Burner	Nozzle-type, shroud covered burner; mixing nozzle enables the oil to be injected into compressed air/water stream that causes atomization of the oil and water providing a clean, cool burn.	0 to 114 m^3/hr oil and debris	1,400 kg	Arctic tests show good results at low temperatures; crude oil, diesel oil, and mud mixtures burn cleanly with or without water; can be mounted on a boom or tripod.
John Zink (Dist. by Baker Tools Co.)	--	Large, open flame burner, high pressure air atomizes oil, high pressure water eliminates smoke; shrouded atomizing head.	0 to 116 m^3/hr	558 kg	Will burn oil containing small bits of rock, sand, and debris, air transportable.
DuPont	Open-pit Incinerator	Retaining wall lined with a cooling wall and tile floor; closely spaced nozzles direct high velocity air over burning zone.	--	Variable	Primarily on-shore device to be located near refinery or harbor; sizes can be ordered to meet specific requirements; may be effective on mousse or residues of burning.
Kenting Oilfield Services, Ltd	Open-pit Incinerator	Pit 2.1 m x 2.7 m x 2.4 m; grate feeder provides continuous loading from hopper.	to 3.2 m^3/hr	14,000 kg	Smokeless pit burner especially good for thick oils (such as Bunker C) with high percentage of water.
TRECAN, Ltd.	Air-Portable open-pit Incinerator	Pit 1.5 m x 3.0 m x 1.5 m assembled from air transportable L-shaped sections weighing 900 kg each; high pressure air added above and below the burning chamber.	1 ton oil debris/hr	9,000 kg	Burner designed for air-transport and rapid assembly in remote arctic areas; designed for burning oiled debris.

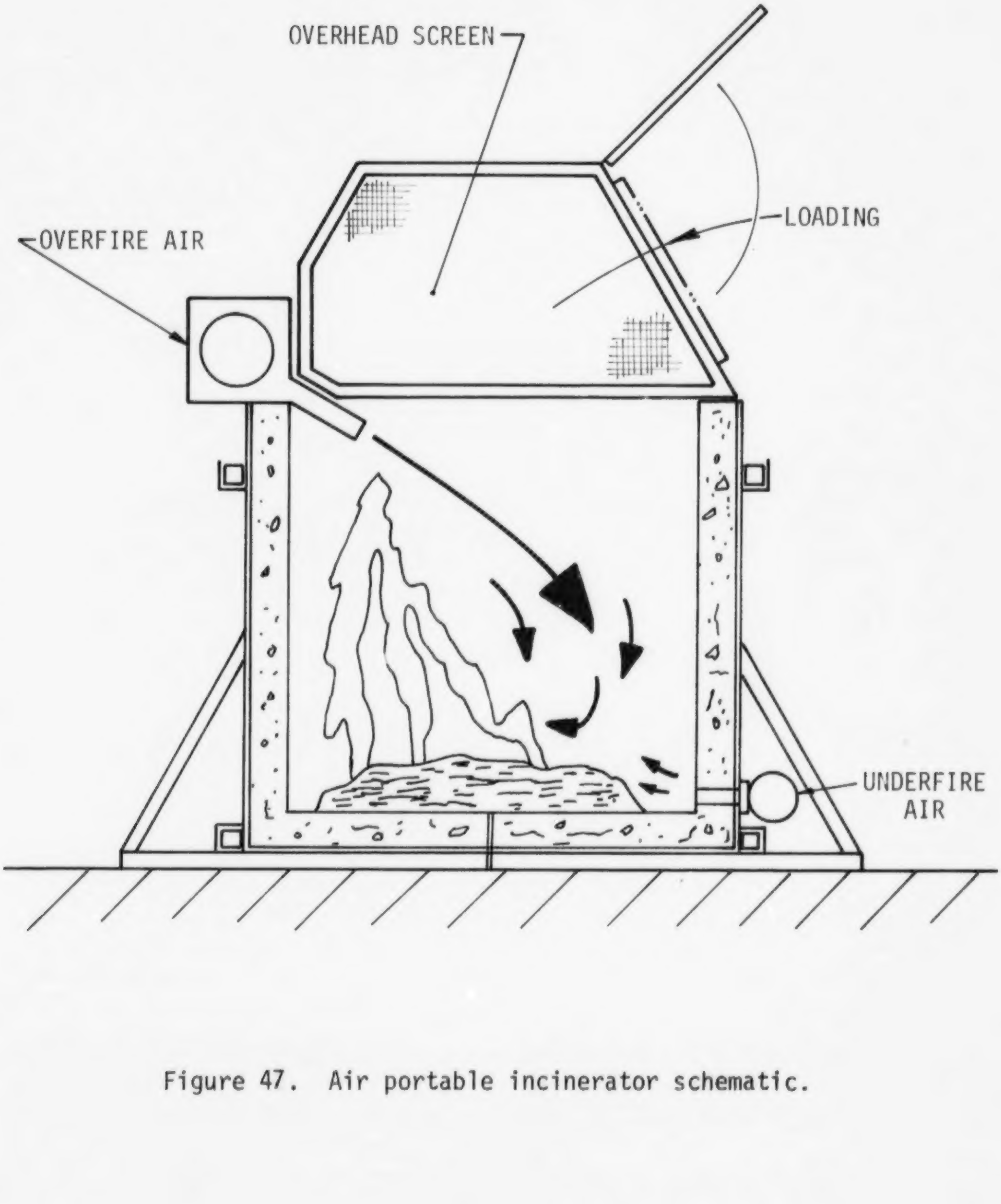
OVERHEAD SCREEN
OVERFIRE AIR
LOADING
UNDERFIRE AIR

Figure 47. Air portable incinerator schematic.

the oiled sand with sheets on a drum. Another device uses an endless chain ramp that carries the oiled sand up to a container. The third device employs rotating discs mounted on an axle. The oiled sand accumulates between the discs which are then wiped clean and the oiled sand is collected. All of these devices performed very well in the laboratory tests and had a high rate of oiled sand pickup. Field tests of these devices were planned for spring of 1979; therefore, a full-scale rotary beach cleaning device may be available soon.

Land Fill--

Both land fill and land spreading are important methods of disposal in the lower 48 states. Land fill is also used to some extent in Alaska, however, many more problems are involved. Land fill in Alaska has the problems of disturbing permafrost layers, chronic erosion where the ground surface has been disturbed, and petroleum products leaching over shallow water tables. Land fill is probably one of the least desirable methods of disposal in Alaska and should only be used when other methods of disposal are not available.

Disposal Requirements

Detailed disposal requirements will be included in the analysis of spill response methods. This section will briefly establish the disposal requirements for each spill scenario in summary form.

Blowout--

This scenario involves the largest spill of oil and also requires the largest effort in the disposal of recovered oil. A large volume of the spilled oil will accumulate in the reserve pit. A large volume of additional highly viscous oil that is scraped off the drill pad and removed from the area beyond the pad will also be stored in the reserve pit until spring breakup. Because so much of this relatively clean oil will be stored in one location, it would be worthwhile to fly in a flaring burner to install it near the reserve pit for the disposal operation. In addition to this relatively clean product stored in the reserve pit, there is also likely to be large amounts of oiled debris that would not be suitable for burning in the open flame burner. A portable open pit burner could be flown in to dispose of this debris. These two burners should be capable of disposing of nearly all of the recovered oil.

Pipeline Spill--

This spill presents a difficult disposal problem. The recovered oil may be accumulated in remote locations that are inaccessible to current disposal devices. A portable open flame burner would be ideal for disposing of relatively clean oil and oil-water mixtures, except such a device is not currently available. Further, many of the areas where the oil is being collected may be inaccessible to vacuum trucks. The recovered oil must therefore be stored in relatively small portable tanks, such as pillow tanks, than removed using some type of off-the-road vehicle or lifted out by a helicopter. The portion of the spill that can be reached by vacuum trucks can be removed by these trucks.

The pipeline spill will also leave miles of oiled beach sand and some oiled debris. A portable open pit burner would be useful to dispose of the oiled debris, but there may be a problem of transporting the oil to the burner. The oiled beach sand may be an even more difficult problem. This sand could be removed by hand and taken to a land fill. Although this has been done for other spills, the removal of the oiled sand is labor intensive and removing the sand from the spill site presents a logistics problem. The prototype beach cleaners described earlier could possibly be used to recover the oiled sand. Once recovered, a portable rotary-kiln burner would be useful to clean the sand so that it could be returned to the shoreline. These two devices are currently not available and therefore represent possible development problems.

Fuel Farm Spill--

The fuel farm spill does not present difficult disposal problems. The product recovered from the water table under the fuel pits can be expected to be relatively clean and ready for use as stove oil after minor polishing. That part of the product that is too contaminated to be cleaned for stove oil can probably be used locally for other purposes such as dust control on local roads. Some sorbents will be used along the edge of the river; these can be destroyed by burning.

Tank Truck Spill--

Product from this relatively small spill will be recovered close to the haul road and therefore can be trucked away. Some oiled debris and vegetation will be collected which can also be removed by truck. A portable open flame burner would be useful in disposing of the recovered product on site if this device were available.

Evaluation of Disposal Systems

Previous paragraphs have described and discussed the methods of disposal that may be considered for remote, inland areas of Alaska. Table 38 summarizes these disposal systems and evaluates them for use in each of the four spill scenarios.

LOGISTICS

Logistics Considerations for Remote Areas

An earlier section of this study describes the transportation facilities that are available in Alaska. This section considers the adequacy of these transportation facilities to meet spill response logistic requirements. For example, the earlier discussion points out that air travel provides a link with the most remote areas of Alaska. Although the use of aircraft does make extremely remote locations accessible to urban areas, there remains the problem of operating into small airfields in hazardous weather conditions. The point is that airfields in remote areas are often not suitable for accommodating the larger aircraft that are required to meet spill response requirements. Further, many remote airfields have no aids to navigation so that aircraft cannot land under instrument conditions. The fact that air travel

TABLE 38 DISPOSAL SYSTEM EVALUATION

DISPOSAL TECHNIQUE	CHARACTERISTICS	PERFORMANCE AND EVALUATION	
Reprocessing Oil is cleaned and used as a primary petroleum product	• Recovered product may be mixed with fresh crude • Must screen debris and separate water • May require emulsion breaking • Simple and often economical	120 to 1000 BBL/day	(1)○ (2)◑ (3)● (4)○
Salvage Recovered oil not suitable for reprocessing but could be used as a lower level petroleum product	• Does not require complex equipment • Economical • Typical uses include road oiling and construction	----	(1)⊗ (2)◑ (3)◑ (4)◑
Open Flame Burning High volume of oil passed through nozzle mixed with air and water mist, and burned	• Emits long flame and much heat • High volume burn • Recovered product can be up to 40% water and mixed with some particulates • Clean burn with no smoke	Up to 12 BBL/min *Spill likely to be inaccessible to burning equipment.	(1)● * (2)◑ (3)⊗ (4)⊗
Incineration Burning using an open pit burner or rotary kiln burner	• Handles oiled debris, oiled sand, and highly viscous residues • High volume • Burners usually large, heavy, and expensive • Smaller versions available but still heavy for inland use • Burn may not be clean	8 BBL/min. oil or 900 kg/hr debris *Rotary kiln for sand and debris	(1)◑ * (2)● (3)⊗ (4)○

(Continued)

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TABLE 38 (Continued)

In-Situ Burning Spilled oil burned without recovery	• May require ignition aids • May be hazardous • Leaves residues that may be difficult to recover and dispose of • May have adverse impact on water, vegetation, or permafrost • Low cost	----	(1)○ (2)○ (3)⊗ (4)◑
Land Forming Oil sludge is spread over soil, cultivated, and decomposed by bacteria	• Oil is applied to soil layer 15 cm deep at 134 l/m^3 (1 gal/ft^3) • Oil is left to decompose for 1 year, land later used for farming • Most successful in warm climates	177 BBL/Hectare/month, minimum temp 10°C	(1)⊗ (2)○ (3)○ (4)○
Land Filling Oil is buried in a pit for decomposition	• Requires designated site • Requires earth moving equipment • May be damaging to environment	Usually large volumes	(1)⊗ (2)◑ (3)○ (4)○

Scenarios

(1) Blowout
(2) Pipeline
(3) Fuel form
(4) Tank truck

● Above average
◑ Average
○ Below average
⊗ Not suitable for indicated application

is common in nearly all populated areas of Alaska does not mean that these areas will generally be able to receive air logistic support for a spill response effort.

Logistic support in remote areas is also highly dependent on off-the-road surface transportation. Although off-the-road vehicles are widely available, the state prohibits all off-road activity north of the Brooks Range from mid-May to mid-July. The problem in the summer is the possible serious erosion of the active permafrost layer. Rolligon movement on the tundra is permitted after July 15 until a stable snow cover is formed in the fall. South of the Brooks Range the Bureau of Land Management has authority to approve off-road travel. The policy in this area is to not allow off-road travel during the summer, and the use of rolligons is not permitted until a 15 to 25 cm cover of snow has accumulated in the fall.

Operating within the framework of the established rules, the spill response specialist must carefully weigh the use of off-road vehicles when their use is permitted with other available alternatives. First of all, the possible impact of vehicle traffic on the environment must be considered relative to the possible impact of the spill. In some cases, the damage caused by the vehicle traffic could be greater than the impact of the spilled oil if no response action were taken.

When the decision has been made to use off-road vehicles, steps can be taken that will minimize the impact of these operations on the environment. For example, instead of simply moving off-road, vehicles can attempt to use existing prepared surfaces such as old survey trails, fire breaks, seismic trails, and other developed access routes (12). Of course, if the vehicles are only used when the ground is frozen, there is less chance of damage. Generally if the surface layer is frozen to a depth of 3 cm there is little danger to the ground, even when using tracked vehicles. Cutting trees and brush to make way for vehicles may have a minimum impact on the terrain providing they are cut and removed in a way that will not disturb the surrounding vegetative mat.

A number of terrain types have special problems, however, and must be avoided. Wetland areas are highly sensitive to any kind of disturbance in the summer and therefore should be avoided. Slopes of greater than 10% are highly sensitive to damage, particularly by tracked vehicles. Sloping areas must be avoided. Riverbanks that consist of fine silt and clay are also highly sensitive to damage. Vehicles should avoid these areas and use instead ground covered by less sensitive gravels and sand. Alpine tundra vegetation is highly sensitive to any kind of disturbance and will not even support light surface traffic without severe damage.

Logistics Requirements

Specific logistics requirements will be addressed as part of each individual spill response method. This section will review some of the general logistics problems that will be encountered in any spill response effort.

The transportation of men and equipment to the spill response base is the first, and primary, logistics problem. The transportation problem, of course, includes both assembling the men and equipment plus loading for transport. Once the spill response base has been established, there will be a continuing task of maintaining the supplies to support the response effort. This means bringing in food, special clothing, additional equipment, expendable recovery materials such as sorbents, and in some cases, transporting the recovered product to a disposal site.

In addition to the task of transporting men and equipment to the spill response site, there is also the problem of transport and logistics support at the spill site. Workmen must be transported from their billeting area to the spill site. Equipment must be transported to various locations on the spill site where it is required. The recovered oil must be transported to a temporary storage area, and if disposal is not occurring on site, it must then be transported away to a final disposal facility.

A number of other support functions must be performed at the site. Although these functions are not all related to transport, they are part of the logistics support requirements. These support services include providing communications equipment and support at the site, providing liaison with, and facilities for, the press if they have reporters at the site. There are also requirements for providing standard housekeeping services at the base camp such as food services, sanitary services, and so forth.

Once the spill response effort has been completed, there are logistic functions to be performed in the stand-down phase, breaking camp, and restoring the area to its normal condition. This task refers to campsite restoration, not spill site restoration. When the spill response effort is completed, there may be a requirement to restore the terrain and the vegetation. The restoration could vary from a minor effort of simply monitoring the area from time to time to see if vegetative cover is returning naturally, to a major effort in tilling, fertilizing, and replanting vegetative cover. Periodic inspection visits to the spill site are likely to be required in any case.

Evaluation of Existing Logistics Capability

A large number of transport vehicles are available in Alaska to meet spill response requirements. Many large transport aircraft are available that are capable of carrying large cubic volume cargo into any airfields that have a runway 4,000 to 5,000 feet long. Military aircraft could probably be made available in the event of a major spill.

Adequate numbers of surface transportation vehicles are also available. Trucks are available from the Alyeska Pipeline Service Company, oil companies, spill contractors, the State of Alaska, and in the event of a large spill emergency, trucks would probably also be available from military bases.

In order to realistically plan a response to the scenarios developed in this study, a complete, current list of all spill response equipment available in Alaska has been obtained from Crowley Environmental Services, Inc. in Anchorage. The data base developed for this list is the standard record of equipment that is used in Alaska by EPA, the State of Alaska, the Trans-Alaska Pipeline, and other spill contractors that operate in Alaska. A separate, current list of equipment available at pipeline pumping stations has also been obtained. These lists are long and take up many pages of a computer printout. For this reason, they will not be included in this report; however, this information will be used to develop the specific spill response methods for each of the oil spill scenarios. That is, for each scenario we will specify the response equipment that is required, we will determine its source from the lists of response equipment, and we will tell how and where it will be delivered to meet the individual remote area requirement. Logistics requirements, then, will be met using real, up-to-date, lists of actual devices that are now available in the field.

SECTION 9

SPILL RESPONSE METHODS AND EFFECTIVENESS ANALYSIS

INTRODUCTION

The preceding sections have described, among other things, the physical environment, the spill scenarios, and the spill response techniques and devices as they apply to the spill scenarios. This section begins by developing a set of spill response methods for each scenario. Next, the cost of each of these response methods is determined. This is followed by an assessment of the impact of each spill as the spill occurs, and after each response procedure has been completed. Then the cost of the response procedure is combined with the change of impact that results from the spill response to determine the cost effectiveness of each of these procedures. The cost effectiveness analysis is followed by a more general effectiveness analysis that considers all elements of the spill response procedure. Finally, a set of R&D initiatives are developed which are designed to improve the response effectiveness for that particular spill response scenario.

These steps are repeated four times in this section, once for each spill response scenario. The first time through, the method of analysis used in each step is described in detail. For example, the discussion of spill response methods for the first scenario will be preceded by a description of how the methods were determined. In the same way, the discussion of the cost for each scenario will be preceded by a description of how the cost was determined, and so forth for the remaining analysis elements. The description of the analysis method will only be provided for the first scenario, however. The analysis of the remaining scenarios will continue by using, but not describing, the method of analysis applied.

SPILL RESPONSE METHODS

Concept Definition

There are a great many spill response methods available for any spill situation. Some of these methods are complete response strategies and some are simply applications of various spill response procedures or combinations of these procedures. Early on it was recognized that the number of spill response methods, or combinations of methods, was too large to develop a definitive analysis for each scenario. As a result, it was decided to instead define spill response levels that would represent an intensity of spill response effort at each level. Each response level would employ the most suitable combination of procedures and devices needed to achieve the desired result. A definition of the response levels will serve to clarify this concept.

RESPONSE LEVEL I

> Minimum Level of Response. Clean up large accumulations of oil near the source of the spill; moderately to lightly oiled areas are left to degrade naturally.

RESPONSE LEVEL II

> Moderate Level of Response. Mount an intensive effort to clean heavily oiled and moderately oiled areas. This response level includes efforts to clean areas where oil is visible, but the recovery rate is low. Leave lightly oiled areas to degrade naturally. This action is taken in addition to procedures for Response Level I.

RESPONSE LEVEL III

> High Level of Response. This effort includes action required for Response Levels I and II plus cleaning all lightly oiled areas. This level of response generally includes an effort to clean all visible or known oil, however, some superficially oiled areas may be left if the environmental hazard of the clean-up effort is judged to be greater than the potential impact of the spilled oil.

Defining these response levels reduces the problem of determining the effectiveness of various spill response procedures to a more manageable task. Each spill scenario has a set of physical characteristics that determines how much of the spilled oil is relatively easy to clean up, more difficult to clean up, or very difficult to clean up. This argument could also be applied to response levels based on areas of high environmental sensitivity, medium sensitivity, or low sensitivity. These criteria are more likely to be applied to an individual spill than an arbitrary decision to recover 20% of the spill, 50% of the spill, or 80% of the spill. Using a predetermined percent of oil to be recovered is generally not consistent with the physical realities of a spill situation on land, and may not meet the requirements of mitigating environmental impact. The definitions of spill response levels used in this study, however, permit a practical approach to the spill response situation. In each case, a decision can be made to clean up areas where recovery procedures are likely to be successful, or to assign a clean-up priority based on the sensitivity of the impacted area. Using this method, each spill situation is studied to determine the natural required levels of effort needed based on the resources available, or to determine the priority based on environmental sensitivity. After identifying the desired levels of response, the best methods of achieving these levels are determined. Many alternatives are considered for achieving each response level, but only one is selected as being the most practical, least damaging to the environment, or least costly. Thus each scenario has a single set of procedures that are used to achieve each response level. A cost is then determined for each procedure, the effectiveness of the procedure is assessed, and the results of the three levels of response are examined together to determine which course of action is most desirable.

For the scenarios developed in this study, it was found that determining the appropriate response actions for each response level was often determined by the physical constraints of the spill situation. For example, a heavy coating of oil on the ground, easily accessible to spill response techniques, will be cleaned up as well as possible. This action is likely to constitute Response Level I. On the other hand, Response Level III is likely to be ordered for a lightly oiled area where response efforts may not be rewarded with much product collected, or where the light coating of oil may have minimal impact. Also, in some lightly oiled areas, the response action itself may be more damaging to the environment than leaving the oil in place. In this situation, the response for that lightly oiled area may not be a part of any of the response levels.

The product must also be available for recovery to be made a part of a response level. Obviously oil that is lost down a swift stream is not available for recovery, and therefore cleaning up this part of the spill is not a part of the designated response levels.

A further restriction on selecting the types of spill response was that the cleanup effort had to be performed with equipment that is presently available in Alaska. In order to fulfill this requirement, a detailed computer printout was obtained from a spill response contractor in Alaska listing all of the spill response equipment available by location. Therefore, when a spill response procedure was selected for these scenarios, the equipment needed for the procedure was selected from the list by model number and quantity. Note was also taken of the location of the equipment and the logistics problems that could be involved in transporting the equipment to the spill site.

The oil spill response methods are selected for each scenario by applying the criteria described defining the spill response levels. The paragraphs that follow begin by applying this system to the exploratory well blowout scenario.

BLOWOUT SCENARIO RESPONSE METHODS

The Blowout Spill Response Problem

Before developing the details of the three levels of response for the blowout scenario, the basic problems and characteristics of the blowout scenario will be reviewed. The reader may wish to briefly review the details of the blowout scenario and the spill behavior in Section 7.

Not much spill response action can be taken before the well is capped. During the blowout oil is accumulating in the area, and because the volatile fractions are still present as it falls, there is a danger of fire and explosion if personnel and equipment are working in the area. Even though very little spill cleanup action can be undertaken while the blowout continues, preparations for the spill response action begin immediately. Personnel and equipment requirements for the spill response action are reviewed. Some additional personnel and equipment are brought to the spill site even though they may not be used until the blowout has been contained. Since there is no way of knowing when the well will be capped, there will be some wasted effort in keeping personnel and equipment standing by until the response effort can begin. This time of waiting will also be used to build a camp and make preparations for the larger spill response effort that will come later.

The blowout described in this scenario occurs in the winter. Since the arctic environment is least sensitive to spilled oil in winter, every effort will be made to clean up the oil while the ground is still frozen. There is no way of knowing that the well will be capped before spring, but the response objective early on will be to complete the cleanup before the thaw.

As the blowout continues, most of the oil falls on the pad. Figure 33 in Section 7 shows the expected spill distribution. Of the oil falling on the pad, more than half of it is deposited in the reserve pit. This occurs because the reserve pit is purposely built downwind from the well. The oil that falls in the reserve pit is recovered as it lands, which helps the recovery problem considerably. Further, since most of the oil falls on the pad, it becomes clear early on that the major spill response effort will require heavy equipment to remove these deposits from the pad. Some of the snow just outside of the pad area is moderately oiled, and the more distant areas are lightly oiled. This indicates that some other type of spill response action will also be required. The oil falling in the very cold winter temperatures becomes highly viscous soon after it hits the ground, and in some cases it sets up into hard lumps. These spill characteristics will also affect the spill response methods to be applied.

This brief review of the spill response problem shows that the response action is likely to involve intensive efforts to clean off the heavy deposits of oil on the pad, and a lower level of effort to clean the more lightly oiled areas away from the pad. Since the most distant areas are lightly oiled, a spill response effort there may be more damaging than leaving the oil in place. These basic problem constraints will now be used to develop specific spill response methods for the blowout scenario.

Blowout Spill Response Methods

Table 39 shows the spill response action that is proposed for each spill response level for the blowout scenario. These spill response methods were developed with the assistance of responsible pollution control officials in the State of Alaska. The methods were developed in a series of intensive

TABLE 39. BLOWOUT SPILL RESPONSE METHODS

	RESPONSE ACTION
RESPONSE LEVEL I	DURING BLOWOUT
• Clean Drill Pad	• Build a snow/ice berm around blowout
• Clean Large Accumulations Off Pad	• Mark outer edge of spill so that it is not hidden by snow
	• Build a spill response camp
	FOLLOWING BLOWOUT - WINTER
	• Clean pad - use tracked vehicles to scrape up hardened oil. Deposit relatively clean oil in reserve pit; burn contaminated oil in portable open pit burner.
	• Clean up large accumulations of oil off pad; deposit in reserve pit or burner.
	FOLLOWING BLOWOUT - SPRING
• Clean Drill Pad	• Clean accumulations on-pad that have become fluid in spring using sorbents.
• Clean Large Accumulations Off Pad	• Clean accumulations off-pad that have become fluid in spring using sorbents.
	• Dispose of oil in reserve pits using open flame burner.
	• Dispose of oiled debris and sorbents in open pit burner.
RESPONSE LEVEL I	SITE RESTORATION:
	• Any oil that remains is left to degrade naturally.
	• Vegetation is left to recover naturally.

(Continued)

TABLE 39. (Continued)

	RESPONSE ACTION
RESPONSE LEVEL II Level I Plus - • Clean Heavily Oiled Snow • Drain Pad	WINTER • Collect and clean heavily oiled snow in the western area from the pad out to a distance of 152 m. SPRING • Drain pad by digging 3 collection trenches at low point. Flush gravel and skim oil from trenches. • Recovered oil transported to reserve pit for disposal with flaring burner. • Dispose of oiled debris in open pit burner.
RESPONSE LEVEL II	SITE RESTORATION • Burn off heavily oiled wet areas off-pad. • Fertilize damaged area from helicopter to speed new growth.
RESPONSE LEVEL III • Clean Lightly Oiled Snow • Polish Gravel on Pad	WINTER • Remove oiled snow from inner area - leave outer area to degrade naturally. SPRING • Remove oiled surface layer of gravel from pad. Clean in snow melter, dispose of oil and water. Return cleaned gravel to pad. • Recover any remaining visible accumulations of oil with sorbents. • Burn oil from reserve pit with flaring burner; dispose of oiled debris in open pit burner.

(Continued)

TABLE 39. (Continued)

	RESPONSE ACTION
RESPONSE LEVEL III	SITE RESTORATION • Action for Levels I and II plus return one year later to see if additional fertilization is required. • Seed arctic grass in areas where there is danger of erosion or thermokarst.

meetings with these officials and the final compromises were reviewed by the senior EPA spill control official in Anchorage. The final result will not, of course, satisfy everyone's concept of what should be done in the selected scenario; however, the result represents the best effort of the most knowledgeable personnel in the field, and should be very close to the result that would be obtained by any experienced spill control specialists after they have had time to consider the problem. The paragraphs that follow describe the spill response actions listed on Table 39 in greater detail so that the reader will have a clear picture of all phases of the response action. This will be followed by a brief discussion of some of the response actions that were considered but rejected. This may be helpful to some readers who have other ideas for response actions to be taken. Of course, a great many other response actions were considered briefly but not recorded here. The reader must be content to know that a wide variety of carefully selected alternatives were considered.

Response Level I--

For the blowout scenario, Response Level I is somewhat complicated by the fact that there are some actions that are taken during the blowout, some following the blowout in the winter, and some following the blowout in the spring. This results in several separate steps to be taken for each response level.

Most of the action taken during the blowout will be concerned with capping the well. Preparations for the major spill response effort will begin, but very little can be accomplished before the well is capped. For example, a snow berm will be constructed around the well to prevent the oil that falls off the pad from spreading. Snow generally acts as a good barrier in cases like these. If the oil is spreading along the ground, it may penetrate the berm for about 10 to 15 cm and then stop. In this case the low air temperatures will probably prevent the oil from spreading, but the berm would still be constructed as a precaution. The berm would be constructed at a considerable distance from the blowout because of the danger of operating equipment close in. Scrapers would be brought in to do this work because the equipment available at the site would be inaccessible during the blowout and would probably not be usable until it had been cleaned some time after the blowout had been capped.

The outer edge of the spilled oil would be marked frequently so that the perimeter of the spill would be known after the oil had penetrated down into the snow or had been covered by blowing snow.

During the blowout preparations would begin for the major spill response effort that would follow. These preparations would include building a camp, bringing the necessary equipment into the area, and planning the response effort. This effort would, of course, result in bringing equipment and personnel into the area long before the response effort could be mounted. This involves some waste, but it cannot be avoided. Some extra personnel must be available to take the initial actions described, and personnel must be available to begin the response effort as soon as the well is capped. The wasted expense of having personnel and equipment waiting would be minimized by beginning with a relatively small crew and making preparations for expanding the force for the larger effort when the blowout had been secured. It is anticipated that twelve additional personnel would be required to take the planned response action during the blowout. Other additional items of support equipment would be required, such as warm-up shelters, living quarters, lighting systems and so forth. No additional support personnel would be required until the more intensive spill response activity begins later.

After the blowout has been capped, the first spill response effort would be to clean the pad of the thick, heavy layer of oil deposited there during the blowout. This would be done using four large scrapers and crews working around the clock. Since most of the oil fell on the pad, this recovery operation would include most of the oil that had been spilled. Since the reserve pit was constructed in an area that is generally downwind from the well, most of the oil on the pad falls in the reserve pit. The reserve pit is large enough to hold all of the oil that fell there during the blowout, all that is scraped from the surface of the pad, and still have the capacity for about 20% more. In this scenario it was estimated that 42,250 barrels fall in the reserve pit during the blowout. An additional 25,860 barrels are recovered by the scrapers and deposited in the reserve pit, and an additional capacity of 26,099 barrels remains without filling the pit beyond a level of 75% of its depth. Some heavily oiled debris would be burned in a portable open pit burner. This would eliminate that part of the spill that would contaminate the reserve pit for other means of disposal later on. No attempt is made to consume all of the oil removed from the pad in the open pit burners because this would far exceed the capacity of the burners and the work crews that would be available. If large accumulations of oil are found off pad, these would also be recovered by the scrapers or crews on foot, and deposited in the reserve pit. No attempt would be made to scrape all of the area off the pad as part of Response Level I.

The spill response action planned after the blowout had been secured would require a work force of about 30 men. In addition to the personnel already in place during the blowout, equipment maintenance personnel would be added, a crew to operate the open pit burner, truck drivers to haul the recovered product to the reserve pit, plus other logistics personnel including medical corpsmen, cooks, and equipment managers. Most of the equipment used for this response effort would be rented. Some items, such as the portable open pit burner, would be purchased because they are expensive to rent and would be used for a long period of time. The open pit burner would cost about $35,000 and would be kept in operation for a long period of time. The trade-offs involved in these types of choices are discussed in greater detail in the section on costs.

As the spring thaw approaches, the spilled oil would become less viscous and some of the oil that was held in place by the ice would be released. The Level I response effort in spring becomes one of recovering newly released oil on and off the pad with sorbents. Most of this effort would still be confined to the pad. A crew of 6 men would be deployed with sorbents off the pad, but great care would be taken in the off-pad effort to be sure that the movement of the crews in the wet areas was not more damaging than leaving the spilled oil in place. The off-pad effort would be limited to areas where there was some accumulation of oil that could be reached without damaging the sensitive tundra. The open pit burner would continue to be used to dispose of oiled debris and the used sorbents. Recovery on-pad during this phase is expected to be about 2,117 barrels; off-pad recovery will only be about 4 barrels.

The major disposal effort in spring would be to burn off the product collected in the reserve pit using an open flame burner. The burner envisioned for this task has a high capacity, up to 1900 liters per minute, and burns with a clean flame. The only burner of this kind that is available in Alaska is owned by ARCO and is used at their facility at Prudhoe Bay. In inquiring about this burner, it was determined that ARCO would lend the burner in the event of a major emergency, and the only cost would be for transportation, operation, and maintenance. The open flame burner is the principal disposal device used in the oil well blowout scenario.

Site restoration for Response Level I would consist of leaving the unrecovered oil in place to degrade naturally, and permitting the vegetation to recover naturally.

Response Level II--

In this scenario Response Level II includes all of the actions that were taken for Response Level I, plus the heavily oiled snow is collected and cleaned. Also in the spring the heavily oiled gravel on the pad is drained and cleaned.

Cleaning the snow is a major problem. At first it seemed reasonable to simply deposit the oiled snow in the reserve pit and wait for the oil and water to separate in the spring. A quick set of calculations, however, showed that the volume of the recovered snow far exceeded the remaining volume in the reserve pit. Some thought was given to attempting to burn the heavily oiled snow in the open pit burner. This was discarded because in general this mixture would probably not sustain combustion, and if it did, the volume of the oiled snow would far exceed the capacity of the available open pit burner. The solution finally accepted was to clean the oiled snow in air berms. An air berm is simply a portable, open pool with inflatable sides. A steam jenny is placed in the berm, then the snow is loaded in, melted, and the oil is removed from the water surface with a portable weir skimmer. This method of cleaning snow has been used successfully in Alaska by spill response contractors and appears to be feasible for the blowout scenario. Experience has shown that each air berm can do three loads in an hour. Using two 2,000 gallon air berms and two 3,000 gallon air berms, which are available in Alaska, the task of cleaning snow for Response Level II could be completed in three days working shifts around the clock. About 7.5 barrels of oil are expected to be collected in cleaning the snow.

In the spring, Response Level II calls for draining and cleaning the gravel pad. Recall that the oil budget in Figure 35 shows that 6,700 barrels of crude oil is estimated to be contained in the gravel pad. In the winter this oil is expected to become highly viscous and therefore stay in place.

In spring the viscosity would decrease with rising temperatures, but even then the oil is not expected to drain out of the pad area. An Alaskan spill response contractor with experience in spill recovery on drilling pads on the north slope reports that there is generally a natural frozen berm along the edge of the raised part of the pad. Figure 48 shows a sketch of how the ice berm has been found to occur. This berm would prevent the oil from draining off the pad area. The contractor indicates that this frozen berm remains intact even in the summer, so that very little oil is expected to seep out of the pad onto the tundra.

The pad would be drained and cleaned by digging three parallel trenches in an area that appears to be a natural low spot. These trenches would be made with one of the scrapers converted to operate as a backhoe. As the thaw progressed, the oil would drain into these trenches. To speed this operation and wash the gravel more thoroughly, the gravel would be flushed using water from an adjacent lake if necessary. As the oil collected in the trenches, it would be recovered with a small rope-mop type skimmer. Three rope-mop devices would be used for this purpose. The recovered oil would be returned to the reserve pit for disposal. It is estimated that this part of the response operation could be completed in about twenty days. About 6,883 barrels of oil are expected to be recovered from the gravel. This is more than the original 6,700 barrels assumed to be contained in the gravel because some of the oil that was left on the surface of the pad after scraping is flushed down and recovered.

Just as in Response Level I, oiled debris would be disposed of in an open pit burner. The major disposal action would consist of emptying the reserve pit using a large flaring burner. These burners have a tremendous capacity for disposal so that operating even at a moderate rate of disposal the oil collected in the reserve pit could be eliminated in about a week, or perhaps a little longer. Since the reserve pit is the normal storage area for waste products, it is not necessary to clean it in the same manner as the pad. Liquid oil is removed from the pit, but when the disposable oil is gone, the operation is complete.

Site restoration following Response Level II may include burning heavily oiled wet areas off-pad. Burning in this area would be applied selectively and carefully. Since the oil would be close to the surface in the wet areas, burning would have a minimum effect on the vegetation and would probably not cause melting of either the permafrost or ice wedges (78). Burning would not be employed in the dry areas, however, because the mosses might be damaged to the extent that they may be slow in returning to normal growth. Burning selectively in heavily oiled areas that are wet enough would be preferrable to recovery by some other mechanical means. Movement of personnel and equipment in these areas would probably be more damaging to the environment than burning, providing the burning is performed selectively, and is carefully monitored.

Site restoration for Response Level II would be completed by light fertilization of the area from a helicopter to speed new growth. The fertilization process would also be carefully controlled; over fertilization

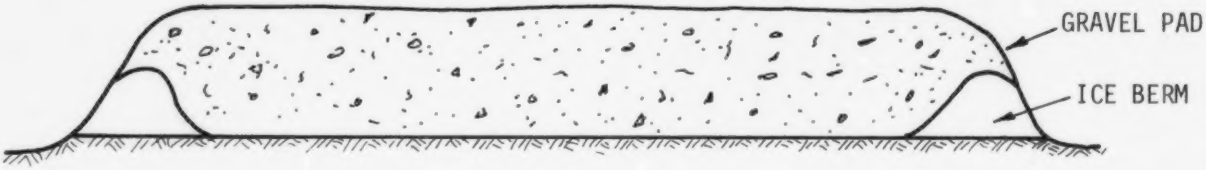
GRAVEL PAD
ICE BERM

Figure 48. Ice berm along the edge of the drill pad.

would be more damaging than leaving the site untreated. The recommended application for this area would be treble super phosphate and ammonium nitrate both at a rate of 100 pounds per acre (78). Fertilization would only be used to speed the growth of damaged vegetation. With fertilization, new growth would be fairly strong in one to two years. Without the fertilization the growth may be delayed to the three to five year range (78).

Response Level III--

This response action represents the final, most thorough cleaning and restoration procedure. In the winter the action includes additional cleaning of snow, in this case the inner two rings as shown in Figure 33. As before, the snow is removed and cleaned in the air berms. About 7.5 additional barrels of oil would be recovered in Response Level III. The very lightly oiled area in the outer ring is left to degrade naturally.

In spring the entire surface layer of gravel is removed from the pad, cleaned in a snow melter, and returned to the pad. The recovered oil is deposited in the reserve pit as before. It is estimated that this recovery action could be completed in a little more than a week and would net another 1,353 barrels of oil. Any remaining visible accumulations of oil would be recovered with sorbents, being careful that additional environmental damage is not done by the work crews. For disposal, clean oil would be burned from the reserve pit and oiled debris would be burned in the open pit burner.

Site restoration would be as in Response Level II except that the site would be revisited a year later to determine if additional fertilizer is required. Arctic grass would be seeded in heavily damaged areas where there is danger of thermokarst activity. The arctic grass would help to preserve that stability of the ground until the natural ground cover had a chance to recover.

Other Blowout Spill Response Methods

It seems likely that many other spill response methods will occur to the reader, therefore a moment will be spent to discuss some of the other response procedures that were considered but rejected.

The pad is the most heavily oiled area and, as a result, the methods suggested for cleaning up this area are likely not to be controversial. Most observers would agree to use heavy equipment to scrape off the deposit of heavy, viscous oil, and to complete the job as nearly as possible in the winter. Removing the gravel to clean it in Response Level III is an extreme measure, and may be judged by some as not worth the effort. It does, however, recover a fairly substantial amount of oil and helps to prevent this oil from leaching out on the tundra later.

Cleaning the oiled snow is one of the largest jobs, and one in which there may be some variations in the method applied. The first response that may occur in dealing with the oiled snow is likely to be to deposit it in the reserve pit and wait for the oil and water to separate in the spring.

A quick set of calculations should dismiss this idea immediately because there is a tremendous volume of oiled snow, far more than could be stored in the reserve pit. Another suggestion may be to develop a snow or ice berm outside of the pad to store the oiled snow until spring. This idea also has problems. Once the oiled snow is stored, some other response action will finally be necessary, action that probably could have been taken in the first place. If the containment berm melts in the spring, the oiled snow may be a new source of pollution as it leaks out on the tundra. In this case the storage may have created a new problem.

Finally, the suggestion was made that the oiled snow be stored on a small frozen lake in the winter. Some disposal procedure could be taken on site, and the oiled snow that remained at spring thaw would at least be contained on the lake and not free to move out to contaminate the tundra. This procedure also has some disadvantages. First, recovery of the oil on the lake may be difficult. Since the entire area is wet, it may be difficult to deploy men and equipment out to the lake to skim the oil. In addition, the lake areas are not well defined. The entire area is wet, and in many cases the lakes run together, and many can be expected to drain into the Meade River. Based on these disadvantages, storage of oiled snow on a lake was also rejected.

Other response alternatives may also occur to the reader. It suffices to say that many alternatives are possible, many were considered in the course of this study and rejected. Some may have merit, but in any case, the alternatives presented here represent a consensus of the authors of the study and the Alaskan spill response specialists who were consulted during the course of the study.

COST OF SPILL RESPONSE

Method of Determining Spill Response Costs

The previous section describes the spill response procedures for each spill response level. This section develops the details for these response procedures and then assigns a cost for each detail. For example, each response procedure is now described in terms of a requirement for:

- Response equipment
- Personnel
- Support equipment
- Transportation/logistics
- Operating/consumables.

First the unit cost or rate of these individual items is determined, then a job performance analysis is completed to determine when each task will begin and how long each task will take. This provides the framework on which a cost analysis can be developed.

The costs for this study were determined using equipment leasing rates and wage rates that were current at the time the cost analysis began in

February 1980. In order to look at the variability of the market for these services, leasing and labor schedules were obtained from two major oil spill contractors based in Anchorage. The costs of consumables, operating fuels, and transportation were also obtained from these contractors. Using these schedules provides what may be considered to be a bid price; however, the final rates may depend on the individual spill situation. For example the costs of leasing heavy equipment, which are often the highest costs for the response procedure, may vary depending on the spill location and the availability of the equipment. If construction activity has been down and equipment has not been in use, leasing rates are likely to be much lower than those shown on the standard price lists. In the case of large spills, equipment is often loaned by other oil companies. When this is done, the only equipment costs are transportation, operation, and maintenance.

These special circumstances tend to make the cost of leasing equipment lower. The other side of the equation, the costs of obtaining equipment and using equipment, are nearly always more than planned. Work may be slowed by weather, personnel problems, breakdowns, and accidents. Estimating the time that is required to perform each response action is also subject to a wide range of errors. The work rates used in this study are based on standard equipment employment schedules and reasonable work rates for personnel. These rates represent baseline conditions. The usefulness of this report is enhanced by the fact that work rates, schedules, and procedures are consistent throughout the study. Even though the absolute values of the response procedures may be subject to fairly wide errors, the relative values are consistent, which permits a valid cost effectiveness analysis.

One additional comment concerning leasing equipment. Some major items of equipment have a high daily leasing rate and are used for a long period of time during the spill response effort. If the equipment is used for a long time, it may be cheaper to purchase the equipment rather than lease it. This situation was recognized for several pieces of response equipment in these scenarios. For example, the portable open pit burner has a leasing cost of about $800 per day and would be used throughout the entire spill response effort. Since the spill response effort would continue for several months, it would be more cost effective to purchase the burners at a cost of about $35,000 each, than to lease them for that period of time. Some other items, such as portable shelters, are also purchased instead of leased.

Labor rates were also taken from the current contractor schedules. In general, workers sent to advanced bases in Alaska are paid for a 12 hour day. This means the wages are for 8 hours of standard rate time and 4 hours of time-and-a-half rate time. This practice is followed in this cost analysis. Whenever the workers are in place, they are paid for a 12 hour day. In many cases the response procedures call for work around the clock. This means two shifts are assigned with each paid for a 12 hour period at the same rate. When the workers are in place but not working, the same wage scales apply. In developing these spill response procedures, some care was taken to only bring in the workers as they are needed and to dismiss them when they are not needed. This kind of scheduling is not always possible.

For example, during the blowout, the initial response crew is brought in as soon as possible. Since there is no way to know when the blowout will be capped, the crew remains in place until the next phase of response begins, even though they are only employed for a few hours a day while the blowout is in progress.

BLOWOUT SCENARIO RESPONSE COSTS

Table 40 shows the cost breakdown for all three levels of response for the oil well blowout scenario. The spill response procedures for this scenario have been described in general terms previously; Table 40 provides the final level of detail and the costs. The paragraphs that follow provide comments on the way in which this detail was developed.

Cost of Response Level I

A small crew of about a dozen men is flown to the spill site soon after the blowout occurs. This crew is composed of just spill response personnel; the requirements for capping the blowout are not considered in this study. Four medium sized scrapers are also flown in to form a snow berm around the spill site and perform any other work that is necessary. Scrapers were available at the site when the blowout occurred, but it is assumed that these vehicles would not be available or usable until much later in the response effort because most of the oil is landing on the pad. The equipment at the pad is assumed to be rehabilitated and put to use much later in the response effort.

The crews and vehicles will only be used for a few hours a day while the blowout is still in progress; however, they must be brought to the site since there is no way of knowing when they will be needed full time. Depending on the urgency felt by the responsible government officials or the outcry of the public, a much larger crew may be sent. A larger crew would increase the expense of the early effort but would do little to increase the effectiveness of the response.

The major spill response effort begins after the well has been capped. At that time additional equipment is brought to the site, and the spill response work force is brought up to the level of about 35 personnel. Based on the spill response work level at that time, this force seems to be large enough. Based on reports of the force level that has been deployed on past spills in Alaska, however, this manning level may seem to be small. The point to be made is this; it is good to have enough personnel, but a massive deployment of manpower may be more damaging to the environment than the spill itself. In remote areas, adequate manning may be far superior to overmanning.

Cost of Response Level II

The use of steam jennies to clean the oiled snow is probably the most innovative response method suggested in Response Level II. This program calls for the use of steam jennies in air berms to melt the oiled snow. The air berms are simply portable pools with inflatable sides. The berms used

TABLE 40. BLOWOUT COST SUMMARY

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
I. *During Blowout*	*Equipment*			
• Build snow berm around spill area	Cat-450	2	16	3,744
	Cat-350	2	16	3,744
• Mark extent of spill	Transport	-	--	15,000
	Operation	-	16	1,400
				23,888
	Personnel			
	Spill control specialist	1	16	8,640
	Cat Drivers	8	16	61,440
	Maintenance	2	--	11,264
	Supervisor	1	--	8,640
		12		89,984
	Support			
	Consumables	-	16	12,480
	Lighting Systems	4	16	2,240
	Generators	4	16	4,160
	Warm-Up Shelters	1	--	2,800*
	Living Quarters	2	--	5,600*
	Cooking Shelter	1	--	2,800*
	Logistics Shelter	1	--	2,800*
	Heaters	5	16	4,000
	Personnel Transport	12	--	2,400
	Equipment Transport	-	--	15,000
	Helicopter	1	4 hrs/day	25,600
	Communications Center	1	16	5,120
	Miscellaneous			3,200
				88,200
Response Level I - Total During Blowout				202,072

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* Purchased

Continued

TABLE 40 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
I, cont'd.				
Following Blowout Winter	*Equipment*			
• Clear pad	"During Blowout" +	-	15	7,020
• Clean accumulations off pad	4 Wheel Drive Trucks	4	15	4,500
	Transport	-	--	15,000
	Open Pit Burner	1	--	35,000*
	Transport	-	--	7,500
	Operation; Cats, Trucks, Pit Burner	-	15	26,528
	Hand Tools	-	9	378
				95,926
	Personnel			
	"During Blowout" +	12	15	84,360
	Open Pit Burner	3	15	13,320
	Truck Drivers	8	15	35,520
	Response Crew	6	9	14,688
	Foreman	1	9	3,672
	Medical	1	9	2,664
	Cook	2	9	5,328
	Logistics	2	9	4,896
		35		164,448
	Support			
	"During Blowout" +	-	15	56,175
	Additional Shelters	5	--	14,000*
	Personnel Transport	-	--	1,800
	Equipment Transport	-	--	30,000
	Helicopter	1	15	24,000
	Twin Otter	1	15	36,000
				161,975
Response Level I - Total Following Blowout, Winter				422,349

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* Purchased

Continued

TABLE 40 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
I, cont'd.				
Following Blowout Spring	*Equipment*			
• Clean Oil Pooled On-Pad	4 Wheel Drive Trucks	2	12	1,800
	D-350 FEL	1	12	1,404
• Clean Oil Pooled Off-Pad	Open Pit Burner	-	12	(1)
	Flaring Burner	-	--	(2)
	Transport	-	--	7,500
• Dispose of Oil in Reserve Pit	Hand Tools	-	12	504
	Operating Costs; Trucks, Cat, Burners	-	12	11,028
	Sorbents, Spill Control Challenger Pads	-	--	50,000
				72,236
	Personnel			
	Cat Drivers	2	12	11,520
	Truck Drivers	2	12	7,104
	Maintenance	1	12	4,224
	Supervisor	1	12	6,480
	Spill Control Specialist	1	12	6,480
	Open Pit Burner	3	12	10,656
	Flaring Burner	3	12	12,672
	Response Crew	6	12	19,584
	Foreman	1	12	4,896
	Medical	1	12	3,552
	Cook	1	12	3,552
	Logistics	1	12	3,264
		12		93,984
	Support			
	"During Blowout" +	-	12	27,180
	Helicopter	-	12	19,200
				46,380
Site Restoration	Any oil that remains is left to degrade naturally. Vegetation is left to recover naturally.			
Response Level I - Total Following Blowout, Spring				212,600

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(1) Open pit burner purchased following blowout.
(2) Flaring burner on loan from operator in Prudhoe Bay.

Continued.

TABLE 40 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
II. Level I +				
Winter	*Equipment*			
• Clean Heavily Oiled Snow	Cat-450	2	3	702
	Cat-350	2	3	702
	4 Wheel Drive Trucks	4	3	900
	Steam Jennies	4	3	2,100
	Air Berms	4	3	480
	Bladder Tanks	4	3	780
	Vac-U-Max Skimmer	4	3	720
	Open Pit Burner	1	3	(1)
	Operating Costs; Cats, Trucks, Jennies, Pit Burner	-	3	8,802
				15,186
	Personnel			
	Cat Drivers	8	3	11,520
	Truck Drivers	8	3	7,104
	Maintenance	2	3	2,112
	Supervisor	1	3	1,620
	Spill Control Specialist	1	3	1,620
	Open Pit Burner	3	3	2,664
	Crew, Air Berms	12	3	9,792
	Foreman	1	3	1,224
	Medical	1	3	888
	Cook	2	3	1,776
	Logistics	2	3	1,632
				41,952
	Support			
	Consumables	-	3	9,495
	Lighting Systems	8	3	840
	Generators	8	3	1,560
	Shelters	3 (add'l)	--	8,400
	Heaters	8	3	1,200
	Personnel Transport	11	--	1,100
	Equipment Transport	-	--	15,000.
	Helicopter	-	3	4,800
	Communications Center	-	3	960
				43,355
Response Level II - Total Following Blowout, Winter				100,493

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(1) Purchased for Response Level I.

Continued.

TABLE 40 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
II. Level I +				
Spring	*Equipment*			
• Drain Pad	CAT-350 Backhoe	1	1	250
	4 Wheel Drive Trucks	4	20	6,000
	CSI Mop Skimmer	3	20	27,600
	Bladder Tanks	6	20	13,200
	Centrifugal Pumps	3	20	4,350
	Open Pit Burner	1	20	(1)
	Flaring Burner	1	1	(2)
	Operating Costs; Cat, Trucks, Burners	-	--	19,766
				71,166
	Personnel			
	Cat Driver	2	1	960
	Truck Drivers	8	20	47,360
	Maintenance	1	20	7,040
	Open Pit Burner	3	20	17,760
	Spill Control Specialist	1	20	10,800
	Foreman	1	20	8,160
	Skimmer Crew	6	20	35,520
	Cook	1	20	5,920
	Medical	1	20	5,920
	Logistics	1	20	5,440
		25		144,880
	Support			
	Consumables	-	--	37,200
	Equipment Transport	-	--	5,000
	Communications Center	1	20	6,400
	Helicopter	1	4	1,600
				50,200
Response Level II - Site Restoration				
	Equipment			
• Burn Heavily Oiled, Wet Areas	Weed Burner	6	4	480
	Fertilizer	-	--	300
• Fertilize Off-Pad	*Personnel*			
	Crew	6	4	6,528
Response Level II - Total Following Blowout, Spring				273,554

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(1) Purchased for Response Level I.
(2) Loaned from Operator at Prudhoe Bay.

Continued.

TABLE 40 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
III. I + II +				
Winter	*Equipment*			
• Clean Lightly Oiled Snow	"Level II, Winter" +	-	8	17,084
	Flaring Burner	-	-	(1)
	Operating Costs; Cats, Trucks, Jennies, Burners	-	8	24,144
				41,228
	Personnel			
	"Level II, Winter"	41	8	111,872
	Support			
	"Level II, Winter" +	-	-	12,160
	Consumables	-	-	25,320
	Helicopter	1	8	12,800
				50,280
Response Level III - Total Following Blowout, Winter				203,380
Spring	*Equipment*			
• Clean Oiled Gravel	D-8 Cat	2	8	(1)
	4 Wheel Drive Trucks	2	8	1,200
	Snow Melter	4	8	(1)
	Bladder Tanks	2	8	1,760
	Pumps	1	8	580
	Open Pit Burner	1	8	(2)
	Flaring Burner	1	8	(3)
	Operating Costs; Cats, Trucks, Burners, Melter	-	-	6,256
				9,796
	Personnel			
	Cat Drivers	4	8	15,360
	Truck Drivers	4	8	9,472
	Maintenance	1	8	2,816
	Open Pit Burner	3	8	7,104
	Spill Control Specialist	1	8	4,320
	Foreman	1	8	3,264
	Snow Melter	8	8	18,944
	Medical	1	8	2,368
	Cook	1	-	2,368
	Logistics	1	8	2,368
				68,384
	Support			
	Consumables	-	8	16,200
	Communications Center	-	8	2,560
				18,760
Response Level III - Site Restoration				8,000
• Return one year later to determine if additional fertilization is required.				
• Seed arctic grass where there is a danger of thermokarst.				
Response Level III - Total Following Blowout, Spring				104,910

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(1) Rehabilitated equipment that was in place at the time of the blowout.
(2) Purchased.
(3) Loaned from operator at Prudhoe Bay.

Continued.

TABLE 40 (continued).

COST TO BREAK CAMP		
Response Level I		
Transport Equipment Out	$ 90,000	
Transport Personnel Out	4,800	
		$ 94,800
Response Level II		
Transport Equipment Out	20,000	
Transport Personnel Out	1,100	
		21,100
Response Level III		
No Additional Equipment or Personnel Required for Level III		
Labor to Break Camp		12,960
Total to Break Camp for Blowout		128,860
Total Cost of Response Levels I, II, and III		$1,648,248

in this operation have a capacity of 2,000 and 3,000 gallons. As the oiled snow is melted, the oil is skimmed from the surface using a Vac-u-max weir skimmer, or similar device, and the water is pumped from below the surface and discarded or held for additional separation. The recovered oil is held in portable bladder tanks on flat bed trucks. Periodically the recovered product is deposited in the reserve pit for disposal. An oil spill contractor has successfully employed steam jennies for cleaning snow in the field, and estimates that each recovery unit could process three loads in an hour. Using two crews working around-the-clock, the entire operation could be completed in about three days. The snow cleaning response would be performed in winter so that the crews could work in the locations where the oiled snow occurs with a minimum amount of damage done to the tundra. The operation would also be completed in the winter so that the oiled snow would not contaminate the tundra in the spring thaw. Some oil would, of course, remain in the snow, however most would be removed. Whatever remained would be left to leach out in the spring and degrade naturally.

The gravel pad would be cleaned by allowing the oil to leach out naturally into trenches. The process would also be accelerated to some extent by flushing. A rope-mop recovery device would be used to pick up the oil in the trenches. This recovery method has been used successfully in Alaska on many occasions. It is estimated that this part of the response would take about 20 days, although the leaching rate near the end of the process is likely to be slow so that it may take somewhat longer to recover the last, small percentage of remaining oil.

Cost of Response Level III

The Response Level III task is the final polishing performed in the spill area. This effort has, almost by definition, a high cost for a relatively small amount of oil recovered. It represents the highest level of response that is possible without causing excessive environmental damage in the course of the recovery effort. Cleaning lightly oiled snow is not likely to cause additional environmental damage since this operation is performed in winter. Cleaning the surface oiled gravel on the pad in the spring may, however, cause a problem. The response procedure calls for removing the surface gravel and cleaning it in a snow melter that has been equipped with a heavy steel basket used to load the gravel in and out. After the spring thaw there may be a problem in finding a suitable place to set up the snow melter, and a way to transport the gravel to the melter and back to the pad, without doing additional environmental damage. This response method would only be successful if all of the cleaning could be done on the unaffected part of the pad.

ENVIRONMENTAL IMPACT OF THE SPILL

Method of Determining Environmental Impact

The chief concern of oil spill response is to reduce the environmental impact that results from the spill. Even though this is the most important part of the entire program, it may be difficult to assess the level of impact that has occurred or, in some cases, even the extent of the impact. Environmental impact must generally be interpreted in terms of damage done to the people who have been affected by the spill. This may be an economic impact, expressed in terms of the loss of property, or the likely loss of expected business, such as the loss of tourist business along an impacted shoreline, or loss of a fish catch in a bay. Also, spill impact may be evaluated in terms of the damage done to water quality, vegetation, or wildlife in areas where there was no specific economic impact. In some cases an underground spill of large proportions can occur and not be detected for a period of many years. This spill may have an adverse effect on the water table or organisms that occur in the area, but this impact cannot be assessed until the spill is known. Further, the extent of the impact cannot be assessed with any degree of precision if the underground area covered by the spill is not known.

In spite of the substantial problems involved in effectively representing oil spill impact, the issue must still be addressed. Methods are needed to evaluate the economic, social, and natural impact of a spill. Further, it is necessary to relate the changes of impact to the spill response effort. And finally, it is necessary to determine the impact of the spill response effort itself. A number of methods for evaluating oil spill impact and spill response effectiveness have been developed. These methods have been applied with a remarkable level of success in some spill situations; however, most researchers admit that there is no universal system that can be applied to all spill situations. The approach must fit the situation. This study uses a single method to evaluate spill impact and response effectiveness, but it is applied in a slightly different way in the various spill scenarios. The method of evaluating the spill impact is described in the paragraphs that follow. The variations in the application of this method will be reviewed as part of the analysis of each scenario.

Assessment of Spill Impact--

This study evaluates the intensity of the spill impact and the response effort by assigning numbers to a set of environmental sensitivity factors to represent the level of impact. Table 41 shows the sensitivity factors selected for use in this study. These sensitivity factors were designed to show the impact the spill has on the environment, the impact the spill has on the economic and social life of the community, and the level of improvement that can be expected from the planned spill response effort. Later the level of improvement will also be linked to the cost of the response effort. The impact of the spill and the response effort is determined for each response level by reviewing the environmental conditions that exist at each of these levels and assigning a number that most nearly characterizes these conditions. The numerical measure of spill impact is assigned on a scale of 0 to 4, with 0 representing no measurable level of impact and 4 representing the most severe impact. Table 42 shows an example of the type of criteria that are used in applying these numbers to sensitivity factors. The Appendix (page 388) shows a complete list of the criteria for applying the numerical measure to all of the sensitivity factors.

TABLE 41. SENSITIVITY FACTORS

PHYSICAL

- Soil stability
- Permafrost

BIOLOGICAL

- Aquatic habitats (fresh)
- Wetland habitats
- Upland habitats (unvegetated)
- Upland habitats (vegetated)
- Finfish
- Birds (water-related)
- Birds (non-water-related)
- Mammals (water-related)
- Mammals (non-water-related)

BIOPHYSICAL

- Wilderness

HUMAN FACTORS

- Human use of minerals*
- Human use of vegetation*
- Human use of fish*
- Human use of birds*
- Human use of mammals*
- Other community activities and/or facilities
- Endangered species
- Aesthetic quality
- Specially designated areas**
- Air quality

* Includes commercial, subsistence, and recreational, each evaluated separately.

** Gravesites, archaeological sites, designated long-term study areas, and parks, refuges, and other legally designated special use areas.

TABLE 42. SAMPLE RATING CRITERIA FOR SPILL SENSITIVITY FACTORS

PHYSICAL FACTORS

Soil Stability - The characteristics of a soil which determine its resistance to such changes as erosion, slumping, or other failure.

0 - No measurable effect

1 - Slight change in stability

2 - Moderate change in stability

3 - Severe change in stability

4 - Extreme to complete change in stability; soil will slump or erode readily without further stimulus

The oil spill sensitivity numbers developed so far apply to a single, isolated area that is being evaluated. The total impact of a spill on an area, however, depends on the amount of oil that was spilled, the area it covers, and the length of time it remains in place. To determine spill impact, then, it is necessary to relate the spill sensitivity numbers to spill volume, area covered, and the length of time that the spill remains in place. In a study of coastal areas performed for the U.S. Coast Guard, ARCTEC developed the following expression for spill impact (79):

$$\text{Impact} = 3 \text{ months } \Sigma \, [\text{Volume} \cdot \text{Area} \cdot \text{Sensitivity}]$$

This particular formulation has the advantage of accounting for residence time, ecological sensitivity, areal coverage of the spill, and the amount of the oil that is involved in the spill. When this expression was used for the coastal study, only the ecological sensitivity was included in the sensitivity index. In our evaluation of inland areas, we also included social and economic sensitivity as part of this index. Thus, the current study uses the same method of determining spill impact, but broadens the concept to include a more detailed description of the spill impact. The current study also includes the effect of spill impact over a period of time, but the assessment over time is not fixed at three months. In one scenario the relatively small tank truck spill is cleaned up in a few days, therefore the impact of the spill, except for the residuals remaining after the response effort is complete, is only felt for a short period of time. This study therefore uses periods of time that correspond to the completion of the three spill response levels instead of the three month interval. Some other variations of this formulation will also be used to meet specific scenario requirements. These variations will be described as they occur.

Effectiveness of Spill Response--

The next step in the spill response analysis employs the numerical representation for spill impact to determine the effectiveness of the spill response effort. A first look at this requirement may suggest that the response effectiveness could simply be represented by comparing the impact with response to the impact if no response occurred. That is, response effectiveness would be represented by the ratio:

$$\frac{\text{Impact with Response}}{\text{Impact with No Response}} .$$

It turns out that this expression, when used alone, is not a good measure of response effectiveness because as the response effort increases this number becomes smaller, and when response is minimal this ratio may approach one. A search for a better expression to represent response effectiveness yielded the following:

$$\text{Response Effectiveness} = 1 - \frac{\text{Impact with Response}}{\text{Impact with No Response}} .$$

This relationship has the advantage of having its maximum value when the impact with response is small (that is, spill response efforts have been highly effective) and a value close to zero for minimal response levels.

This definition of response effectiveness was developed for offshore and coastal situations where spill response efforts are not likely to be damaging to the environment. For an inland case, a misdirected spill response effort could be more damaging to the environment than the spill itself. Although one would avoid embarking on a spill response effort that would have this effect, this result would be represented in the response effectiveness expression as a negative number. This result will identify that particular effort as the least desirable response.

In many cases there is extensive evaporation of the spilled petroleum product after the spill, both before the response action begins and while the response action is in progress. In the case of a gasoline spill, it may not be safe to employ conventional spill response devices. Often the spilled gasoline may be gone before a spill response effort can be mounted. Even crude oil may evaporate 20 to 40 percent of the original volume within a few days. In all cases, the effect of evaporation must be considered in determining response effectiveness.

The additional detail that should be considered in the response effectiveness evaluation includes the social and economic sensitivity to a spill, and the effect of product evaporation on the response effectiveness computation. To account for these details, consider again the expression for spill impact:

$$\text{Impact} = \sum_{i=1}^{\text{Time}} \text{Vol}_i \cdot \text{Area}_i \cdot S_i$$

where

Vol_i = initial spill volume + continued leakage volume - evaporated oil - recovered oil

Area_i = initial spill area + continued leakage area - evaporation loss - recovered oil

S_i = combined environmental and social sensitivity factor for each period of time.

ENVIRONMENTAL IMPACT OF THE BLOWOUT

The expression for spill impact developed above is represented as the product of the volume spilled, the area covered, and the spill sensitivity. When using this expression for marine and aquatic spills, the area covered by the spill can be perceived to change incrementally based on the spill response effort, evaporation rate, or other form of dispersal. For example, after the slick thickness has stabilized on water and the volume of the spill is not increasing, a response effort that recovers 25% of the oil spilled can also be considered to have reduced the area of the spill on the water by 25%. This reasoning is useful for the application of the formula but it may not always be valid for a spill on land. For the blowout scenario, Response Level I cleans up a volume of oil from the ground, but the ground area cannot be considered to be clean as in the case of a water surface where the oil has been removed. The ground is still oiled, and an additional volume is also recovered in Response Levels II and III. Because of this particular feature of a spill on ground, the area of the spill is assumed to remain constant for the blowout scenario. The spill impact for the blowout is therefore a function of the volume of oil that remains on the ground, and the sensitivity of the environment to that volume.

Table 43 shows the spill sensitivity for each environmental factor determined to suffer an impact and for each spill response level, including the initial condition, or zero level of response. This table was prepared by a group of environmental biologists and geologists at the Arctic Environmental Information and Data Center (AEIDC), Anchorage, Alaska. This group was given the full details of each spill scenario and the actions that would be taken for the three levels of spill response. The group then determined the spill sensitivity evaluation number and the rationale that led to assigning that number to each sensitivity factor and spill response level. The spill sensitivity number assigned is shown in the parenthesis with each sensitivity factor. In the blowout scenario, these numbers were then combined with the volume of oil that would remain after each spill response level to determine the environmental impact of the spill.

EFFECTIVENESS OF BLOWOUT SPILL RESPONSE

The effectiveness of spill response for the blowout scenario is a function of the volume of spill remaining on the ground and the sensitivity of the various environmental factors to this volume of oil. Table 43 shows the sensitivity factors for each response level. This section will determine the volume of oil that remains after each response action is complete. This volume is used with the sensitivity numbers to determine spill impact and spill response effectiveness.

Figure 33 shows that a measurable amount of oil coats the ground within a radius of 928 m of the well head. The area coated, then, is 2.71×10^6 m^2.

Next consider the volume of oil remaining after each spill response procedure. Figure 35 shows the distribution of the oil during the first 30 days if no spill response action is taken. This is the starting point for determining the volume remaining after each response action has been completed. Since evaporation continues during the response effort, it has been assumed that half of the amount of oil recovered during the response effort is available for evaporation during the time the recovery is taking place. This reduces both the amount of oil available for recovery and the amount recovered. The paragraphs that follow show the amount of oil recovered during each response procedure and the amount of oil remaining when the response procedure is completed. These numbers provide a record of the results of each response effort.

TABLE 43 OIL WELL BLOWOUT SPILL SENSITIVITY

	NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Soil Stability	(4) As days lengthen, oil would warm and spread over a broad area, probably eventually into Meade River. Albedo change would degrade permafrost and lead to massive soil instability and eventual downslope movement. This would continue for many years. Oil might accelerate thaw, lake coalescense and/or drainage, and rejuvenate local drainage channels.	(4) Albedo severely reduced by compaction of vegetation and oil stain. Oil in sand and gravels would travel along permafrost table, emerging in low-lying areas and leading to severe slumping.
Permafrost	(4) Same as above	(4) Same as above
Acquatic Habitats (fresh)	(4) As oil warms in spring and flows outward, degrading permafrost and cutting channels in surrounding soils, it would completely cover the large lakes in the vicinity, eventually cutting through to the Meade River through existing partial channels. Relatively small amount would enter the river. Lake habitats would be destroyed for a long period. Effects in the river would be slight but prolonged.	(4) Oil remaining in ground or at surface would cover shallow lakes, destroying habitat. Some would reach the Meade River.

(Continued)

TABLE 43 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Soil Stability	
(4) Some reduction of albedo change, considerable reduction in quantity of oil moving laterally at surface of permafrost table. Added activity of heavy equipment and people adds to instability.	(4) Although the reduction in oil remaining is considerable, the additional activity in the area contributes to instability.
Permafrost	
(4) Same as above.	(4) Same as above.
Acquatic Habitats (fresh)	
(3) Considerable reduction of oil that would reach the lakes and river. Disturbance of soil from heavy equipment activity would cause erosion and siltation of lakes and rivers.	(3) The reduction in oil pollution would be balanced by an increase in surface disturbance.

(Continued)

TABLE 43 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Wetland Habitats	
(4) Wetlands affected by the spill would be severely inundated by relatively fresh oil as it warmed in spring. Toxic elements in the oil would kill all organisms. Soil instability would prolong the effects over a number of years.	(4) Oil still remaining in ground and at surface would destroy wetland vegetation over a reduced area. Disturbance by heavy machinery and human activity would destroy additional vegetation.
Upland Habitats (unvegetated)	
(4) Oil would penetrate throughout active dunes as it warmed in spring. The soil stability would be reduced by the oil and by permafrost degradation owing to albedo reduction.	(4) Soil instability and presence of oil in and under dunes would render these habitats unusable.
Upland Habitats (vegetated)	
(4) Oil would kill vegetation and animals in affected habitats. Continued permafrost degradation and soil instability assure long-term total damage.	(4) Oil on surface and in soil would cause soil instability and kill vegetation over a broad area. Reduction in amounts of oil would be offset by equipment activity and camp.
Finfish	
(3) Usually no fish in lakes of this area. As oil reached the Meade River, it would be somewhat weathered and the highly water soluble toxic elements would be largely dissipated. Seepage into the river at this point would be long-lasting, however, and cumulative damage to fish, primarily ciscoes, other whitefish, grayling, and burbot, would occur.	(2) Reduction in oil reaching river would benefit fish.

(Continued)

TABLE 43 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Wetland Habitats	
(3) Additional oil removed and site restoration would hasten recovery.	(3) Some additional, but slight, benefits from additional oil removal and revegetation effort.
Upland Habitats (unvegetated)	
(3) Oil in dunes would be reduced. Heavy equipment movement would partially offset this reduction in damage.	(3) More reduction in oiling of dunes, but equipment movement would be increased.
Upland Habitats (vegetated)	
(3) Oil on surface and in soil would be reduced. Damage from vehicles and camp would be partially offset by use of fertilizer.	(3) There would be little added benefit from removing more oil. Added activity would intensify damage.
Finfish	
(1) Further reduction of oil in river would reduce damage.	(1) There would still be enough oil reaching the river to produce slight long-term adverse effects.

(Continued)

TABLE 43 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Birds (water-related)	
(4) Many birds would immerse themselves in the oil with fatal results. Others would be precluded from nesting, feeding, or molting in the spill area. Ducks, geese, shorebirds, loons, jaegers, gulls, and terns would be affected.	(3) Fewer birds would contact oil. Effects on nesting and feeding use would not be reduced because of human activity.
Birds (non-water-related)	
(2) Few birds would become contaminated. Of those that did, many would die, however. Use of the area for nesting or feeding would be precluded. Snowy owl use of sand dunes would be curtailed. Some raptors would be poisoned by eating contaminated prey.	(2) Little actual damage to birds, but human activity would preclude use of the area.
Mammals (non-water-related)	
(3) Complete mortality of lemmings and voles. Ground squirrels driven from their burrows. Scavenging foxes, wolves, and bears would be affected by contaminated carrion. Caribou would be denied use of the habitat. Fox denning habitat in affected sand dunes would be destroyed.	(4) Decrease in amount of oil would be offset by the vehicle movements and camp activities that would have a temporary devastating effect on small mammals.
Wilderness	
(1) Wilderness qualities of Meade River downstream from the spill would be slightly impaired for an extended period.	(3) Effect of major movement of men and machines would eliminate wilderness character of surrounding area.

(Continued)

TABLE 43 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Birds (water-related)	
(3) Damage to wetland habitats would be reduced because of fertilization but would remain severe enough to preclude use of a year or more.	(3) Same as II at left.
Birds (non-water-related)	
(2) Same as I at left.	(2) Same as I at left.
Mammals (non-water-related)	
(3) Use of fertilizer and removal of oil would more than offset the short-term damage to small mammals.	(3) Further oil removal would have little significant effect.
Wilderness	
(3) Increased use of machinery would intensify effect on wilderness.	(3) Same as II at left.

(Continued)

TABLE 43 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Human Domestic Use of Water	
(2) Meade River would become unsafe for drinking when oil reached it and would remain so for an extended period. Use of Meade River water for drinking is probably low, however.	(2) Enough oil would reach Meade River to make it unfit for drinking for an extended period.
Human Use of Vegetation	
(2) Use of spill area for gathering roots and berries foreclosed. Only very slight effects on this activity downstream on the Meade River.	(3) The cleanup action would not improve the vegetation for human use.
Human Use of Fish	
(4) Fish downstream in the Meade River would be unsuitable for most uses for several years. The rating of 4 is given because of the importance of the Meade River as a fishing area for residents of Barrow and Atkasook.	(4) Enough oil would still get into the Meade River to render fish unsuitable for human use.
Human Use of Mammals	
(2) Virtually all mammals using the spill area of the downstream Meade River would be tainted to some degree. Value of furs would be severely diminished and some meat would be inedible.	(1) Cleanup would be sufficient to limit effects of oil on meat or furs to small amounts that they would pick up from the river. Presence of men and machines would prevent contamination in spill area.

(Continued)

TABLE 43 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Human Domestic Use of Water	
(1) Meade River would remain tainted, but would be safe for human consumption except for a small distance downstream from the spill.	(1) Same as II at left.
Human Use of Vegetation	
(2) The cleanup action would not improve the vegetation for human use.	(2) Same as II at left. Arctic grass used in reseeding would not be useful to humans.
Human Use of Fish	
(3) Reduction of oil flowing into Meade River would be sufficient to reduce damage.	(1) Further reduction of oil in the river would reduce damage to fishery. Fish would still be tainted.
Human Use of Mammals	
(0) Sufficient reduction in oil in Meade River to preclude significant effects.	(0) Same as II at left.

(Continued)

TABLE 43 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Other Community Activities and Facilities	
(3) The North Slope Borough maintains an outdoor educational facility on Meade River. The river is also used for camping and social outdoor use by Barrow residents. These activities would be severely impaired.	(2) Presence of oil at educational facility would be reduced, but would still be significant based on effects on fish distribution and acquatic biota.
Aesthetic Quality	
(3) Entire spill area would be covered with oil. Downstream Meade River would be affected for a period of years.	(2) Spill area would still be seriously affected. Recovery of Meade River would be accelerated.
Specially Designated Areas	
(3) NPRA is specially designated for oil exploration. However, this activity is to be conducted without adverse effects on other resource values. These other values would be severely diminished at the spill site.	(3) Reduction in values would be diminished by cleanup efforts, but would still be severe.
Air Quality	
(1) There would be a persistent odor of oil at the spill site and downstream on the Meade River for a period of months.	(1) Burning of large amounts of oil in an open pit would cause air pollution.

(Continued)

TABLE 43 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Other Community Activities and Facilities	
(1) Further reduction of oil in Meade River would reduce effects to slight impairment.	(1) No further reduction of impairment.
Aesthetic Quality	
(1) Recovery of spill area would be hastened, as would downstream Meade River.	(1) No further significant benefits.
Specially Designated Areas	
(2) Further amelioration of value reduction by cleanup and site restoration.	(2) No further significant benefits.
Air Quality	
(2) Increased burning would prolong adverse effects	(2) Same as II at left.

Volume of Oil Recovered and Remaining Following Each Response Level

The following briefly summarizes the calculations that were made to determine the volume of oil remaining following the completion of the effort for each response level. These numbers are then used to calculate spill response effectiveness.

Response Level 0--

Volume remaining after 20 days = 84,780 BBL or 1.34×10^4 m^3.

Response Level I--

Winter	
Oil in reserve pit	42,250 BBL
75% of 34,480 BBL on pad recovered	25,860 BBL
50% of 8,620 BBL remaining recovered by work crews	4,310 BBL
20% pooled off-pad recovered	5 BBL
Spring	
50% of 4,223 BBL that becomes liquid on pad in spring	2,117 BBL
20% of accumulations that become liquid off-pad in spring	4 BBL
TOTAL RECOVERED, RESPONSE LEVEL I	74,546 BBL (11,851.5 m^3)

Response Level I Summary	
Oil available for recovery	83,430 BBL
Oil recovered	74,546 BBL
Oil remaining after Response Level I	8,884 BBL (1,412.6 m^3)

Response Level II--

The oil recovered during Response Level II is in addition to the amount recovered during Response Level I.

Winter	
75% of 10 BBL available in heavily oiled snow	7.5 BBL
Spring	
Flush pad and collect oil from gravel (oil originally in gravel and some of the surface oil that is flushed into the gravel)	6,883 BBL
TOTAL RECOVERED, RESPONSE LEVEL II	6,891 BBL (1,095.5 m^3)

Response Level II Summary

Oil available for recovery (after evaporation)	8,807 BBL
Oil recovered	6,891 BBL
Oil remaining after Response Level II	1,916 BBL (304.6 m^3)

Response Level III--

The oil recovered during Response Level III is in addition to the amount recovered during Response Levels I and II.

Winter	
75% of 10 BBL available in moderately oiled snow	7.5 BBL
Spring	
Remove and clean surface gravel on pad; 70% of 1,933 BBL available	1,353 BBL
TOTAL RECOVERED, RESPONSE LEVEL III	1,361 BBL (216.4 m^3)

Response Level III Summary

Oil available for recovery	1,916 BBL
Oil recovered	1,361 BBL
Oil remaining after Response Level III	555 BBL (88.2 m^3)

Blowout Spill Response Effectiveness

Spill response effectiveness is determined by first computing the spill impact for each response level using the expression:

$$\text{Impact} = \text{Volume Spilled} \cdot \text{Area} \cdot \text{Sensitivity}.$$

In this case the volume is the volume remaining after each response action has been completed, the area is the total area covered by the spill, and the sensitivity is represented by the sensitivity factors shown on Table 43. The appropriate spill volume and area are multiplied by each sensitivity factor shown on Table 43, and the sum of these products is a measure of the spill impact at each response level. The numbers representing spill impact are than combined according to the formula:

$$\text{Response Effectiveness} = 1 - \frac{\text{Impact with Response}}{\text{Impact with No Response}}$$

to determine the response effectiveness for each response level. Table 44 shows the results of these computations.

TABLE 44 BLOWOUT SPILL IMPACT AND RESPONSE EFFECTIVENESS

Response Level	0	I	II	III
Impact (m^5)	$2.079 \cdot 10^{12}$	$2.178 \cdot 10^{11}$	$3.626 \cdot 10^{10}$	$1.003 \cdot 10^{10}$
Response Effectiveness	--	0.895	0.983	0.995

One may immediately note that the response effectiveness shown in Table 44 is very high, since a response effectiveness of 1.0 would be considered to be perfect. This result is probably as much a function of the scenario characteristics as it is of the response effort. In this scenario, the blowout occurs on land in the winter, therefore very little of the spilled product is lost to recovery. Nearly all of the spill is accessible to a response procedure, and because the ground is frozen, it is relatively easy to recover. As always, recovering the last small amount of oil requires a massive effort, but to a large extent even this last small amount of oil is available to recovery if the commitment is made to recover it.

Another important characteristic of the blowout scenario is that about 50% of the amount of oil available for recovery falls in the reserve pit, which is, by definition, recovered as it lands. This also has a significant affect on response effectiveness. The reserve pit was designed to contain a spill, but the effect is still to skew the analysis. It is difficult to compare this spill response situation to the more familiar spill situation offshore or in an aquatic environment where a spill response action must be taken quickly or most of the spill is lost to recovery. Offshore the percent recovery may be in the 10 to 30 percent range, and any measure of response effectiveness would be much lower. In the blowout scenario most of the oil is on the pad waiting to be recovered. In fact, most of the oil must be recovered if the pad is to be used again for its intended purpose.

Percent spill recovery is quite high for all of the response levels in the blowout scenario. As a result, the spill response levels were defined as the minimum level of response acceptable, a moderate level of response, and a high level of response, rather than on a predetermined percent recovery. These definitions were developed because of the overriding operational requirements of the spill response situation. There is no point in looking at a 50% recovery level arbitrarily when the pad area, which contains most of the spilled oil, must be cleaned if it is ever to be used again or the environmental threat to the local area is to be removed. Because of this typical characteristic of inland spills, most of the graphs illustrating response effectiveness are plotted against spill response level rather than percent recovery. The fact that the percent recovery for all response levels is high is not significant; these response levels were determined for other, practical reasons and are, therefore, the points at which response effectiveness should be examined.

Figure 49 shows a plot of the spill response effectiveness for each response level. This curve shows that a relatively high level of effectiveness is achieved with Response Level I, and that the improvements in this measure of effectiveness for Response Levels II and III are relatively minor. This is the basic message in the analysis of the blowout scenario. This observation will be illustrated in a number of other ways in the paragraphs that follow.

COST EFFECTIVENESS OF BLOWOUT SPILL RESPONSE

The cost effectiveness of spill response will be determined using the expression:

$$\text{Cost Effectiveness} = \frac{\text{Normalized Cost}}{\text{Response Effectiveness}}.$$

This formula is the basic representation of cost effectiveness, but since the response effectiveness is characteristically high for the blowout scenario, the cost effectiveness cannot be expected to change much for the three spill response levels. Because of this, a number of other relationships are also developed in the analysis to illustrate how the final result is influenced by the spill response effort.

The normalized cost shown in the formula is the total cost of each response level divided by the total cost of the entire operation. Recall also that each response level describes actions that are taken in addition to the response levels that preceded it; therefore the costs associated with the response levels are cumulative.

Figure 50 shows a plot of cost effectiveness for each spill response level. Since this curve has no minima, the most cost effective solution is Response Level I, which is the minimum level of effort. The points on this curve show a greater dispersion than for response effectiveness shown in Figure 49, but the interpretation is the same. Response effectiveness changes very little between response levels, but cost does; therefore the cost effectiveness, which is simply the quotient of these two terms, rises more steeply than the response effectiveness alone. This shows that cost is increasing much more rapidly than effectiveness as response levels are added.

The point has often been made that the cost of picking up the last little bit of oil is high. This is another lesson of this particular analysis. The magnitude of this relationship will be emphasized with two additional curves.

Figure 51 shows the cost/barrel of oil recovered for each spill response level. In this case this is the additional cost for each response level divided by the additional barrels of oil recovered. This curve shows that the cost per barrel of oil recovered increases from about $13 per barrel in Response Level I to about $227 per barrel in Response Level III. This again emphasizes the high cost of picking up the residues of a spill.

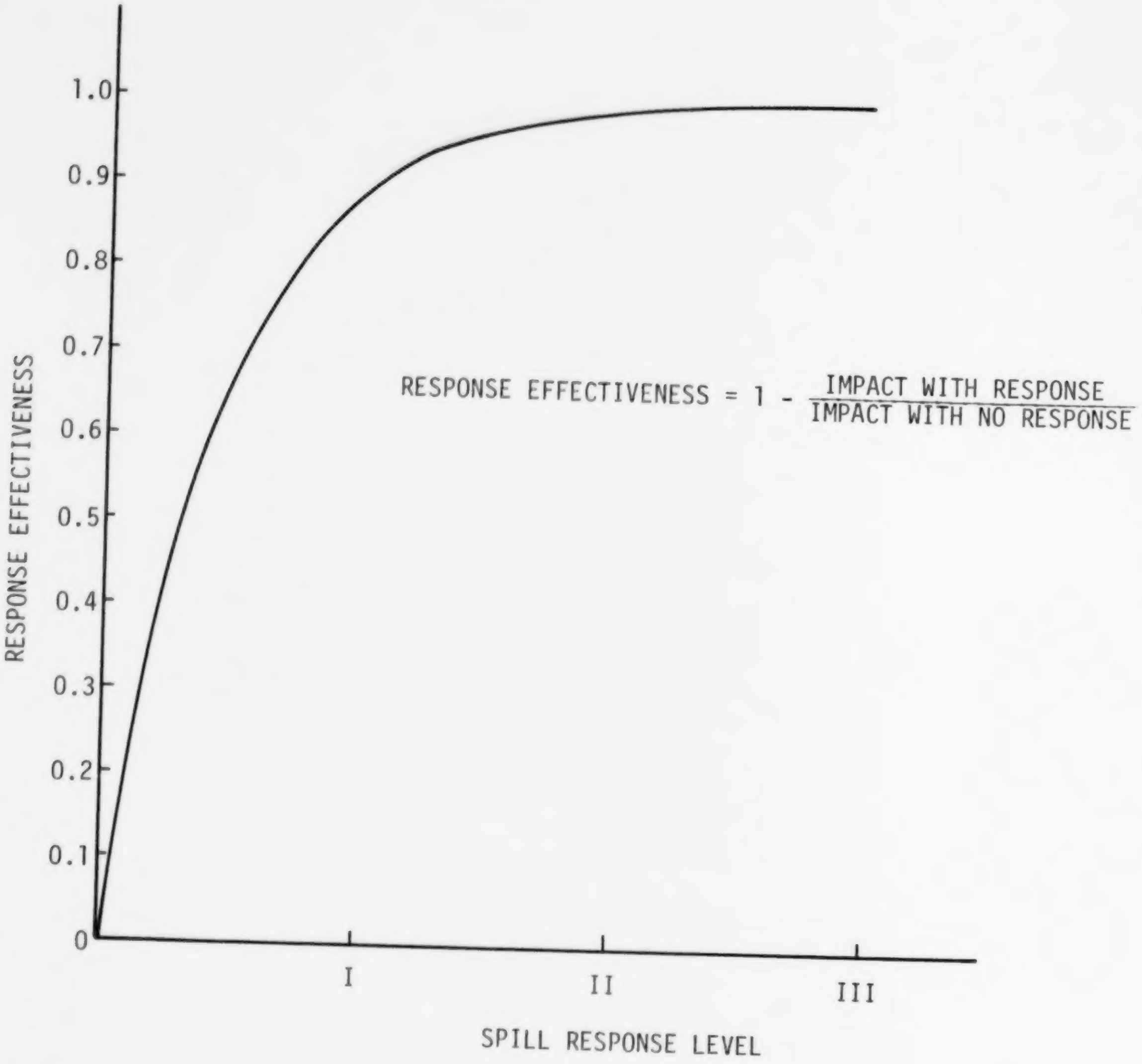

Figure 49. Blowout scenario response effectiveness vs response level.

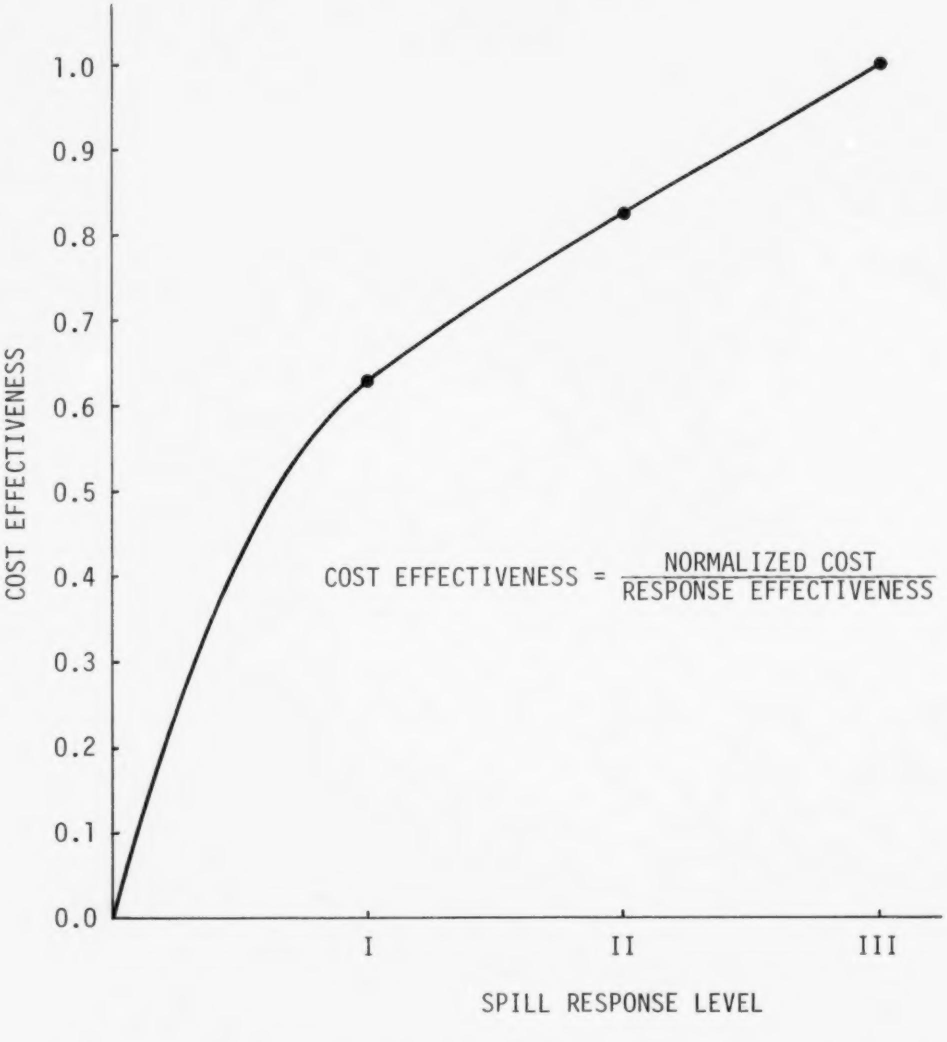

Figure 50. Blowout scenario cost effectiveness vs spill response level.

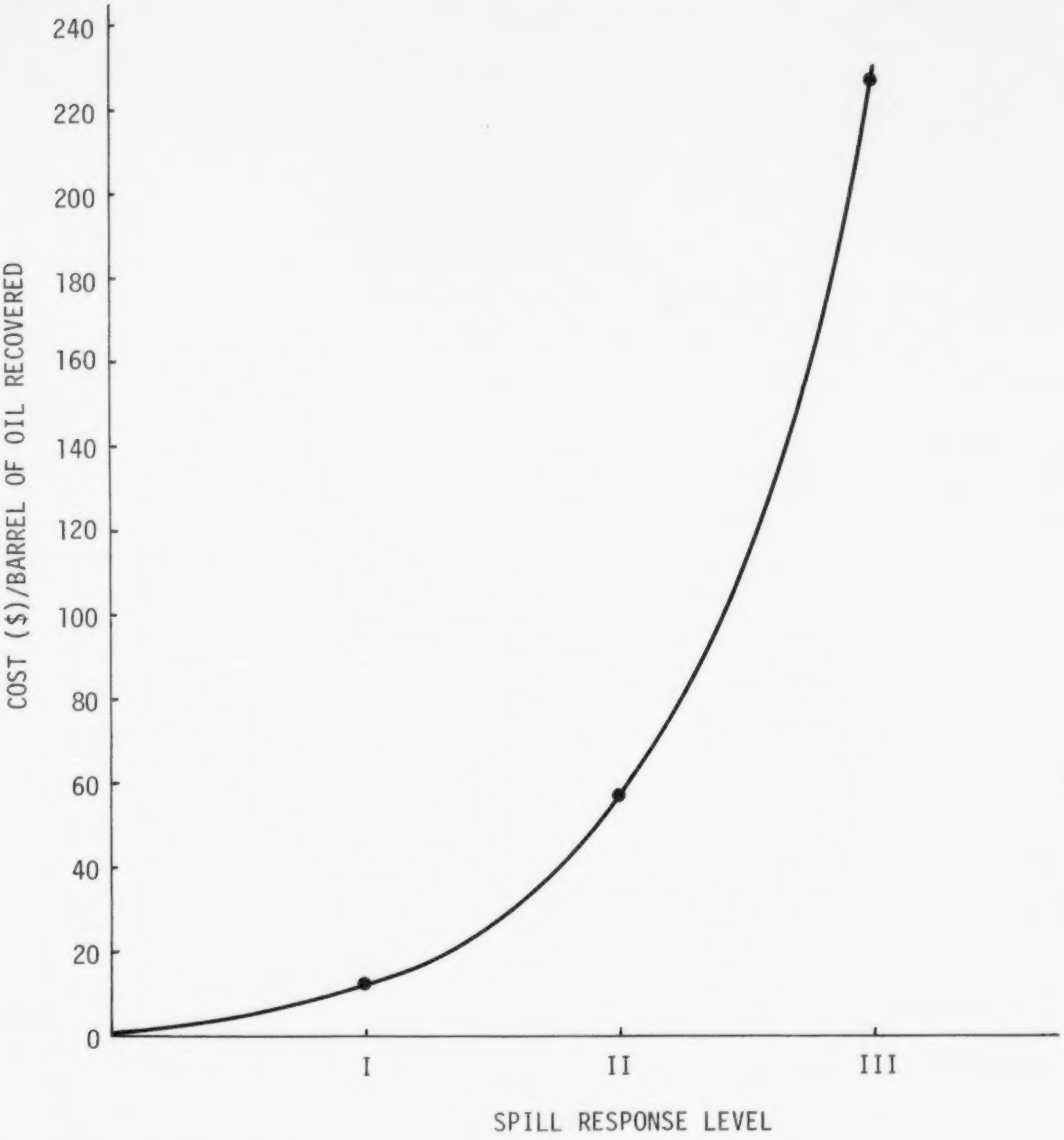

Figure 51. Blowout cost/barrel of oil recovered vs spill response level.

Figure 52 shows a plot of percent impact removed for each spill response level. This figure, in effect, summarizes and emphasizes the points made previously. Figure 52 shows that 90% of the assessed spill impact is removed in Response Level I at a cost of \$10.5K for each percent removed. This can be compared with 9% of the impact removed at a cost of \$43.9K for each percent in Response Level II, and only 1% of the impact removed in Response Level III at a cost of \$308.3K for that single percentage point.

Summary of the Blowout Effectiveness Analysis

The effectiveness analysis presented so far assumes that the numbers used in the analysis are typical of real world conditions. The reader must be cautioned that although the numbers were developed with great care, they were determined using a spill scenario which is, at best, only a simulation of real world conditions. This results in some problems of scenario artificialities. For example, the absolute cost of the various response levels is likely to be low using a spill scenario. The numbers developed here represent actual equipment lease rates, actual labor rates, and costs of transportation, but in this analysis the researcher has perfect knowledge of how much equipment and how many personnel are required to do the job. The real world spill control manager does not have perfect information and, as a result, he may often have more personnel and equipment than are really needed. This, of course, results in a much higher expense to perform the response action than described in this report. Costs of performing spill response tasks are also likely to be higher than expected because of problems encountered in the field. This study does account for a small percent cost overrun for each response activity, but major, costly problems cannot be anticipated.

In spill response analysis, there is always a problem in determining a good numerical measure of spill impact. Since a rigorous definition of spill impact cannot be offered, the best situation the analyst can hope for is to be able to develop a system that can show relative levels of spill impact and changes in this impact that result from the response effort. This is the approach used in this study. The system devised in this study appears to be basically sound, although it may be considered to be more sensitive to changes in spill volumes than to changes in environmental sensitivity. This is probably a criticism that could be made of any system of measuring spill impact, particularly when large volumes of oil are involved and when spill response procedures result in large changes in the volume of the spill remaining. In defense of the system used in this study, it can be said that the relative level of impact and the changes in levels of impact are represented, which is likely to be the most that any system can offer.

Now consider the results of the analysis of the blowout scenario. This analysis supports a position that the minimum required level of response is both the most cost effective and the most practical. This does tend to be true for this particular spill scenario, however this conclusion should be softened somewhat by some important qualifications.

The blowout scenario is unusual in that most of the spill falls on the pad where it is easily accessible to spill response efforts. In fact,

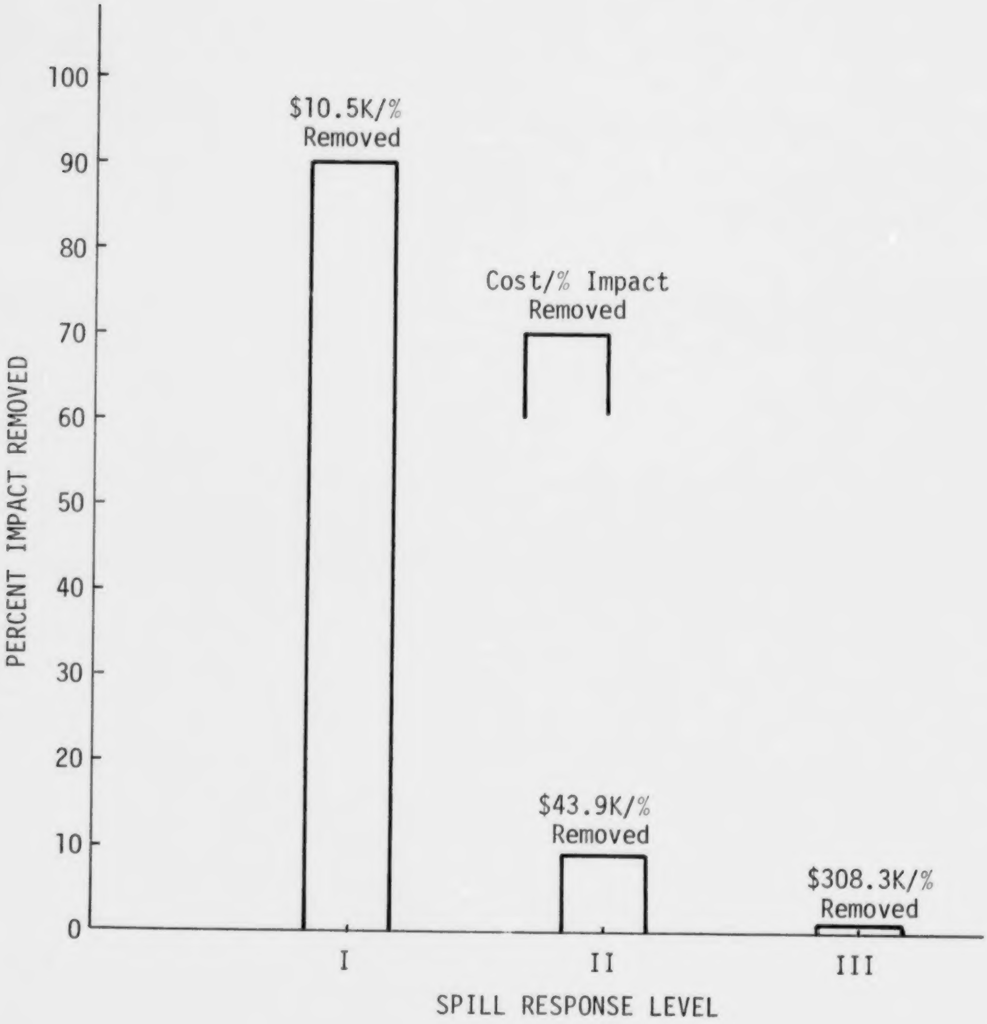

Figure 52. Blowout percent impact removed vs spill response level.

more than half of the oil falls in the reserve pit and therefore is "recovered" as it lands. Further, the vast majority of this oil on the pad must be removed if operations on the drill pad are to continue, therefore the minimum acceptable level of response is very high indeed and likely to show up as the most cost effective approach. The cost effectiveness of Response Level I is also enhanced by the fact that most of the oil on the pad can be removed fairly easily with a scraper and disposed of in the reserve pit only a short distance away. This also results in a large amount of the spill being collected for a low cost and therefore presents itself as the most cost effective response alternative. The reader must be reminded, therefore, that the blowout scenario as described in this study is a special situation. This analysis does not suggest that the minimum level of response is always the cost effective alternative or the most reasonable course of action.

Yet despite these cautions, most analysts and observers in the field will agree that the final massive spill response effort launched to recover a small amount of spill remaining is often neither cost effective nor practical. In fact, final efforts to polish the last remaining traces of the spill may be labor intensive or machinery intensive, or both, with the result that the response effort is far more damaging to the environment than leaving the oil in place to degrade naturally. This condition is recognized by the environmentalists from AEIDC with the comments under Response Level III in Table 43 such as, "The reduction in oil pollution would be balanced by an increase in surface disturbance", or "Disturbance by heavy machinery and human activity would destroy additional vegetation". This represents just a sampling of such comments as presented in Table 43. It suffices to say that Response Level III was not designed to have this effect, but for many spill sensitivity parameters it does. The point to be made is this: if after completing Response Level II agreement can be reached between the spill response managers and the responsible government officials that additional spill response effort would have a low level of productivity, or that additional efforts may even have an adverse effect on the environment, then the decision may be made to eliminate the final response level. This is perhaps the final lesson to be learned from the scenario; that intensive response efforts on a diminishing quantity of spilled oil may be counterproductive.

R&D INITIATIVES TO IMPROVE BLOWOUT RESPONSE EFFECTIVENESS

Method of Identifying R&D Initiatives

In developing spill response procedures, a number of specific tasks were identified that could have been performed more efficiently if more suitable equipment were available. These cases have therefore been developed to identify areas in which R&D initiatives could improve the spill response performance. This section suggests possible R&D initiatives to support the oil well blowout scenario. A similar section will be included along with the analysis of each of the other scenarios. The final section of the study will review the R&D initiatives developed in each of the scenarios and establish a set of priorities for the development effort.

R&D Initiatives Suggested by the Blowout Scenario

Response Level I--

There is a requirement in this scenario to dispose of large volumes of recovered oil in the reserve pit and also a requirement to dispose of smaller quantities of oil off-pad that result from the snow-cleaning effort. The oil in the reserve pit can be burned off cleanly using a large flaring burner. This type of burner is currently available at Prudhoe Bay, and although it may be difficult to transport to a remote area, it would be satisfactory to perform the desired task.

There is, however, a requirement for a similar, but smaller, flaring burner to dispose of the oil recovered from the snow on site. Having several small flaring burners that could be used on site would speed the recovery process and reduce the requirement for moving personnel and heavy equipment over the frozen ground.

Response Level II--

Cleaning oiled snow is one of the major recovery activities in Response Level II. Melting the oiled snow using a steam jenny and air berm is an innovative, practical solution to the problem; however, the procedure is relatively slow, labor intensive, and therefore expensive. Cleaning or disposing of oiled snow is a problem that comes up in nearly every winter spill situation in Alaska. As a result, developing a device designed to perform this task is a top priority project.

Response Level III--

There is currently no standard method of cleaning oiled sand and gravel. In this scenario the pad gravel is cleaned by fabricating a steel mesh screen to hold the gravel in a snow melter. This approach to the problem is innovative but not particularly efficient. A better system is needed for cleaning sand and gravel.

PIPELINE SCENARIO RESPONSE METHODS

The Pipeline Spill Response Problem

The pipeline spill is discovered as breakup occurs. As a result, the spill response effort, and even the repair of the pipeline, cannot begin until breakup is complete and the ice is gone. Breakup does occur quickly, however, and this section of the Koyukuk River can be expected to be clear in a period of two or three days.

Although no response action can be taken immediately, preparations for the response action and repair of the pipeline would begin as soon as the leak is discovered. The pipeline would be shut down and crews and equipment would be moved to the spill site at once. The initial effort would be to repair the pipe to stop the flow and attempt to halt the flow of spilled oil in the vicinity of the leak. In spring the river would be most sensitive to the impact of the spilled oil, but it would be difficult to keep the oil from moving directly into the water. Further, once the oil is in the water, it would be difficult to collect it for recovery because most containment booms and other recovery devices are not effective in the swift currents expected during breakup.

As the river recedes just after breakup, the spilled oil is expected to coat the shoreline. This will present the second major spill response problem. Cleaning the shoreline would be difficult, labor intensive, and the cleanup effort could result in another impact to the environment.

The paragraphs that follow describe the specific spill response actions that are planned for the pipeline spill scenario.

Pipeline Spill Response Methods

Table 45 summarizes the spill response methods that are proposed for the pipeline spill. As before, these mehtods were developed with the assistance of federal and state spill response officials in Alaska plus a spill response contractor in Anchorage. The paragraphs that follow provide additional detail concerning these response methods.

Response Level I--

Response Level I includes three basic response actions:

- Protecting the spill site
- Cleaning the spill site
- Cleaning the beach downstream.

First consider the task of protecting the spill site. Because the river is in flood stage just after breakup, the spill site must be protected so that the pipeline can be repaired and the spill can be controlled at the source. The plan for response level I provides for protecting the spill site with a berm constructed in the river upstream from the spill site. This berm would direct the flow of the river around the source of the spill onto the broad flood plains and abandon meander on the opposite bank. Figure 53 shows possible locations for the berms relative to the area where the spill occurred. The exact location of the berm would depend on local conditions. More than one berm might also be employed. The river flow can be expected to be heavy at breakup and the river may also contain heavy debris such as trees and stumps. The berm would be constructed using a large scraper and front end loader in the river digging out the river bottom to form the berm.

While the berm is being constructed upstream, a backhoe would begin digging a bell hole around the pipe in the area where it has cracked. This hole would be deep enough to expose the pipe well above the water and oil that would collect in the bottom of the hole. The bell hole would be expected to contain a heavy concentration of spilled oil which would be removed using a vacuum truck and a small Manta Ray skimmer head on the spill surface. Because of safety considerations, repairing the pipe might be delayed until the highly volatile crude is collected out of the hole.

TABLE 45. PIPELINE SPILL RESPONSE METHODS

	RESPONSE ACTION
RESPONSE LEVEL I	
• Divert Stream Around Spill Area	• Develop a berm upstream of the spill to divert river away from spill.
• Clean Original Spill Site	• Dig a "bell hole" around where pipe has cracked for repair.
• Clean Heavily Oiled Beach	• Wash soil and collect oil in pit.
	• Pump water out of bell hole; skim oil from surface.
	• Deploy boom parallel to shore just outside shore. Collect oil in a pond at "J" hook at downstream end.
	• Remove heavily oiled beach using crews with hand tools. Haul oiled sand and debris to disposal site for burning.
RESPONSE LEVEL I	SITE RESTORATION
	• Leave unrecovered oil to degrade naturally.
RESPONSE LEVEL II	
Level I Plus -	
• Clean Lightly Oiled Beach Downstream	• Deploy crews up to 20 miles downstream; clean heavily oiled or highly sensitive areas.
• Remove Oiled Logs and Debris	• Lift out oiled logs and debris; if possible; burn on sand bar in river.
• Recover Oil Pooled in Still Areas Along the Shore	• Deploy men with skimmers to recover oil pooled in slack water.
RESPONSE LEVEL II	SITE RESTORATION
	• Recover oiled logs and debris. Unrecovered oil left to degrade naturally.

(Continued)

TABLE 45. (Continued)

	RESPONSE ACTION
RESPONSE LEVEL III	
• Recover Oil Spilled in River	• Dig scallops in river bank and deploy a log or berm just ahead; use a boom downstream when feasible.
• Polish Beach	• Deploy work crews with sorbents to clean patches of oil and wipe down rocks and trees.
• Cut and Dispose of Oiled Vegetation	• Cut heavily oiled low vegetation; cut down heavily oiled trees and dispose by burning.
RESPONSE LEVEL III	SITE RESTORATION
	• Cut and burn oiled vegetation to make way for more rapid growth of follow-on vegetation.
	• Fertilize and seed separately damaged areas that may be subject to erosion or thermokarst damage.

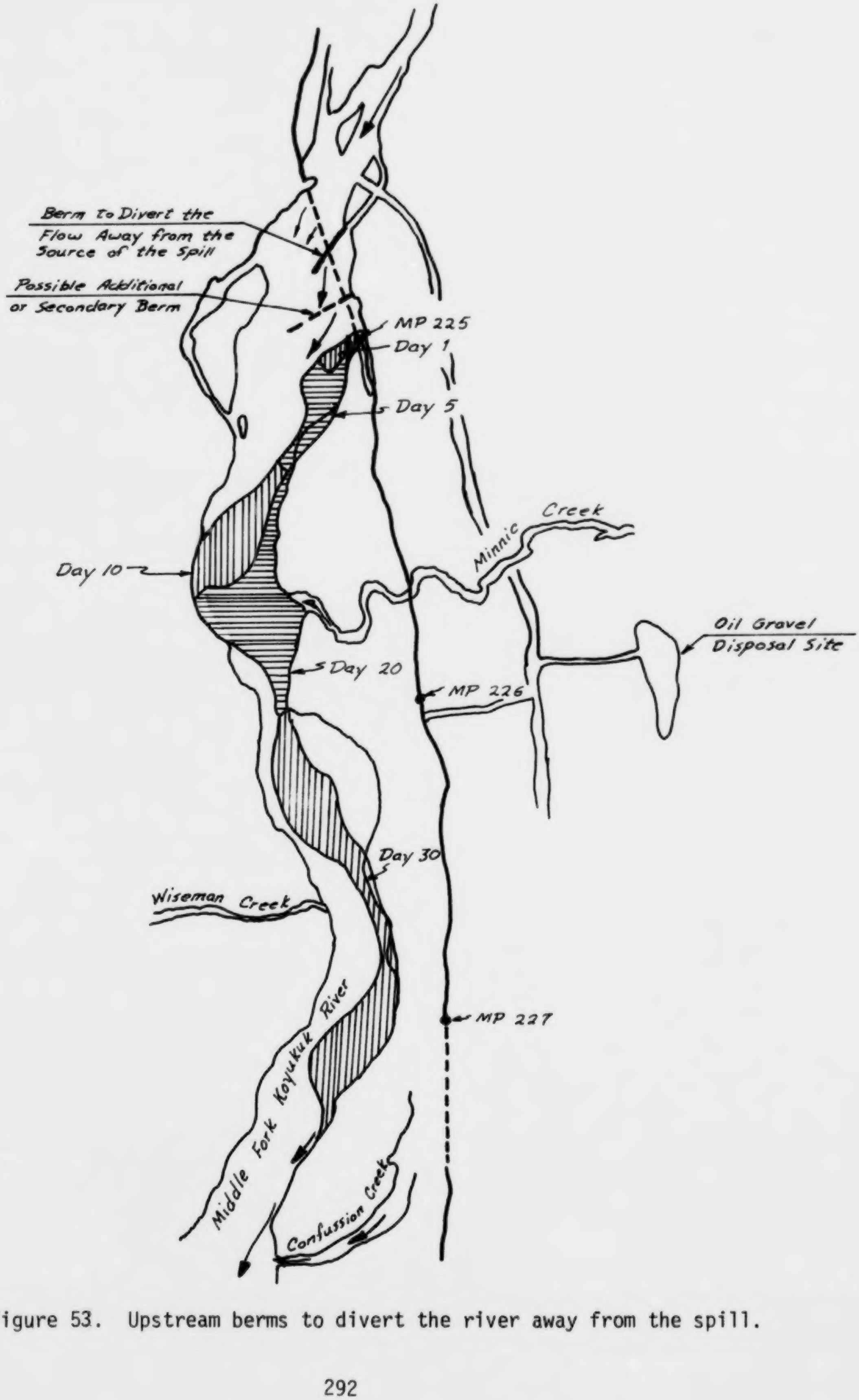
Berm to Divert the Flow Away from the Source of the Spill
Possible Additional or Secondary Berm
MP 225
Day 1
Day 5
Day 10
Day 20
Day 30
Minnie Creek
Oil Gravel Disposal Site
MP 226
MP 227
Wiseman Creek
Middle Fork Koyukuk River
Confussion Creek

Figure 53. Upstream berms to divert the river away from the spill.

All of the ground in the area of the spill is expected to be heavily oiled down to a depth of several meters. To clean this ground, river water would be pumped up to flush out the soil. A trench would be dug down slope near the edge of the river to collect the oil washed down by the flushing operation. The trench would be lined with plastic to help retain the oil. A rope-mop recovery device would be used to skim the oil off the water collecting in the pit.

In spite of these recovery measures, a large volume of oil could be expected to be leaching into the river at the spill site. The flood stage of the river makes this oil difficult to retain and recover. The spill response action in the river would be designed to contain and recover as much of this oil as possible. The general condition of the river at flood stage is such that it would not normally be possible to deploy a boom and successfully contain the oil. By building a berm in the river upstream of the spill site, there is a chance that the velocity of the flow behind the berm will be reduced enough to deploy a boom and contain, or at least successfully divert, the spilled oil. It is therefore proposed to deploy a boom parallel to the shoreline just outboard of the spill to prevent the oil from immediately spreading across the river. If this operation proved to be successful, the downstream end of the boom would be secured ashore in a "J" hook drawing the oil into a natural or specially constructed collection pond. This boom deployment would have to be made in a location of opportunity. The spill response manager would select a location where a large volume of the product was moving into the river, where the flow was well protected by the upstream berm, and where the boom could be successfully deployed to divert the oil into a collection pond. The details of this boom deployment would be planned on site.

The spill response activity away from the spill site is concentrated on cleaning the heavily oiled beach downstream of the spill. Although this action is not as urgent as the cleanup at the spill site, the downstream cleanup could occur concurrently as manpower became available.

The actual cleanup operations that occur downstream depend to a large extent on the type of shoreline that is encountered. The basic response program is to clean the heavily oiled sand. This would be performed by work crews on foot because the rugged nature of the shoreline would prevent the use of heavy equipment. The proposed effort involves eight 6 man crews removing oiled sand and gravel in the area from the spill to about 16 km downstream. Where the shoreline is sand and light gravel, the crews would collect the oiled sand in windrows using drag boards as scrapers. The oiled sand would then be shoveled into plastic bags and removed by helicopter to a disposal site. The proposed disposal site is shown in Figure 53. Permission would be obtained to burn the heavily oiled sand at the disposal site and bury the residues in a pit. The finer oiled sand could also be spread on the haul road for dust control. Using the eight crews, it is estimated that the shoreline could be cleaned in about 15 days.

The dragboard collection and recovery system would only be possible in areas where the shoreline is composed of sand and fairly small gravels.

Some of the river banks are likely to be too steep to clean and in many areas the gravels may be too large to collect. In these areas a different plan for spill response would be required. Oil that has pooled in areas where large rocks occur could be collected by crews using sorbents. In some cases large boulders could be wiped down with sorbents. Areas that contain heavy gravel that has been oiled present a different problem. Portable pumps could be employed in these areas to flush the gravel, but this procedure would have the disadvantage of moving the spilled oil into a highly sensitive stream. A better course of action would be to leave the oiled gravel to degrade naturally. This would have the advantage of keeping the relatively fresh oil out of the stream during the current spring season. This oil may still be in place for the next spring flood, but by then the oil would be highly weathered, not as likely to be carried away with the currents, and far less toxic. The disadvantage, of course, is that the oiled gravel would remain contaminated for a fairly long period of time. This trade-off, however, seems to be more acceptable than flushing the fresh crude right into the stream.

Site restoration for Response Level I would simply consist of letting the oil degrade naturally.

Response Level II--

Response Level II includes all of the actions that were described for Response Level I plus the lightly oiled beach is cleaned downstream, oiled logs and debris are recovered, and an effort is made to recover oil ponded in slack water areas. The effort to clean the original spill site that began in Response Level I continues through Response Levels II and III.

Cleaning the lightly oiled beaches downstream is performed by four 6-man crews that are deployed up to 32 km downstream in a helicopter. As before, these crews collect oiled sand and light gravel using hand tools. The oiled materials are loaded in plastic bags and removed by helicopter to the disposal site. The success of this operation would depend, to a large extent, on the condition of the beaches and the accessibility of these areas to the work crews. Since this effort involves cleaning lightly oiled areas at a greater distance far from the spill, the amount of oil recovered is expected to be smaller. As a rough estimate, only about 13 barrels of oil is expected to be recovered in this operation. In practice, this effort would only continue if it were successful. For this scenario, it is planned to clean the lightly oiled shorelines for a period of three days.

Next, heavily oiled logs and debris would be removed for disposal. This would be accomplished by loading the materials into a helo sling and transporting them to a disposal site. If possible, a gravel or sand bar would be found mid-stream where the logs and debris would be deposited for burning. An isolated sand bar on the river bank would be used if an island was not available. The objective of this effort is to remove the heavily oiled materials so that in periods of high water they would not continue to feed oil into the stream. This effort emphasizes removal of heavily oiled materials because some observers believe that the removal may be more disturbing to the environment than leaving these materials in place.

The disposal of these materials also presents some problems. The burning operation will be accompanied by large amounts of black smoke, which changes a water pollution problem to an air pollution problem. It may be pointed out, however, that the air pollution is likely to be brief and less damaging to the environment in this remote area than the pollution that would be caused in the water. The burn would also have some residue that would be a pollutant, although the volume of the residues would be fairly small.

The debris removal proposal proved to be a controversial measure among the spill control authorities and environmentalists in Alaska. Some of the environmentalists felt that it would be less damaging to leave the oiled logs and debris in place. They held that by removing these materials you were disturbing the environment and disrupting the habitat for mammals. They believe that leaving the logs in place, even if they are oiled, is better than removing them.

This is an issue that cannot be resolved here and probably must be decided on a case-by-case basis. It may be noted here, however, that burning of any kind, even at a disposal site, is a highly controversial issue among Alaskans. This question appears to require additional study to develop guidelines for disposal by burning that can be used by spill response managers in the field.

The final action for Response Level II would be to send crews with skimmers out to recover oil pooled in slack water areas. Two crews of six men each would be deployed by helicopter to locations where the oil is visible and recoverable. Each two man team would be equipped with a Morris MI-2 (small) disc skimmer and a 5 gallon can to hold the oil. This is planned as a one day operation. The object of this effort would be to remove visible oil where it occurs; the return in product collected would be very small.

Site restoration would consist of recovery of the oiled logs and debris. Unrecovered oil would be left to degrade naturally.

Response Level III--

This response level provides the final polishing effort that is intended to remove as much of the spilled product remaining as possible. The spill response procedures include collecting oil from the river, a final polishing of the shoreline, and cutting and removing heavily oiled vegetation. Recovering the oil remaining at the original spill site would continue.

Although the oil spilled in the river is likely to have the highest level of environmental impact, it is also the most difficult to collect and probably will result in the lowest rate of return for the response effort. At breakup the Koyukuk River is expected to have a maximum average velocity of nearly 4 knots (see Table 17). Except for areas where velocities can be found to be much lower than this, the use of containment booms is not likely to be successful. This response effort will therefore concentrate on selected areas where oil is collecting naturally and where the river velocities are low enough to permit the use of containment booms. The use of unconventional containment schemes may also be effective. For example, Alaskan spill response contractors have successfully recovered oil by digging collection pools in the riverbank and then constructing a berm or deploying a log just upstream of the pool. This system will slow the flow of the oil and collect it in the dead space behind the log, and in the collection pool. If possible, a boom would be deployed just downstream of the berm to help divert the oil into the collection pool. Figure 54 shows a sketch of the planned arrangement. The oil in the collection pool would be recovered using a small disc skimmer, such as the Morris MI-2. Booms would also be deployed downstream in areas where oil is gathering and current velocities would permit their use. This operation is planned to occupy the response crews for a period of two days. The rope-mop recovery could possibly be used in the swift currents by deploying the rope at an acute angle to the river and running the rope downstream to reduce the relative velocity to the river. The return rope would be lifted out of the river to prevent the collected oil from being washed off.

After the crews recovered all the available oil from the river, two additional days would be spent polishing the shoreline. The crews would use sorbents to collect oil pooled in isolated areas and wipe down heavily oiled rocks and trees.

The final Level III activity would consist of cutting heavily oiled low vegetation and heavily oiled trees. This debris would be lifted with the helo to a gravel island in the river for burning.

As expected, there are some disadvantages to the proposed recovery program. Response Level III, as defined by this study, is always the final polishing effort. This therefore involves a rather intensive effort to recover a small amount of oil. In every case the question must be asked, is the intensive effort more damaging to the environment than leaving a small amount of oil in place? In the case of a spill on land, the final polishing effort may, in fact, be quite damaging to the environment. For the pipeline spill, there is some question about digging the collection pools in the river bank. Some observers believe that this action is more damaging than leaving the oil to continue downstream. It is probably a question of degree. If a reasonable amount of oil can be collected, it may be worth it. This, of course, requires that someone be on hand to make the decision. The collection pools in the river bank may not be damaging in the long term because the river is extremely dynamic, and likely to fill the collection pools with sediment or remove them in a short time. Those who believe this are likely to also believe that the pools are not damaging and the collection effort is worth the possible impact.

Cutting oiled vegetation and trees is also a controversial issue. The purpose of this procedure is to remove oil that will later recontaminate the river. Those who oppose this action believe that the trees are better left in place even if they are oiled. Even if the oil kills the tree, they believe that the tree will be replaced by new growth just as well as if it had been removed, and the undesirable impact of the removal process is avoided. This particular procedure was proposed because the preponderance of evidence

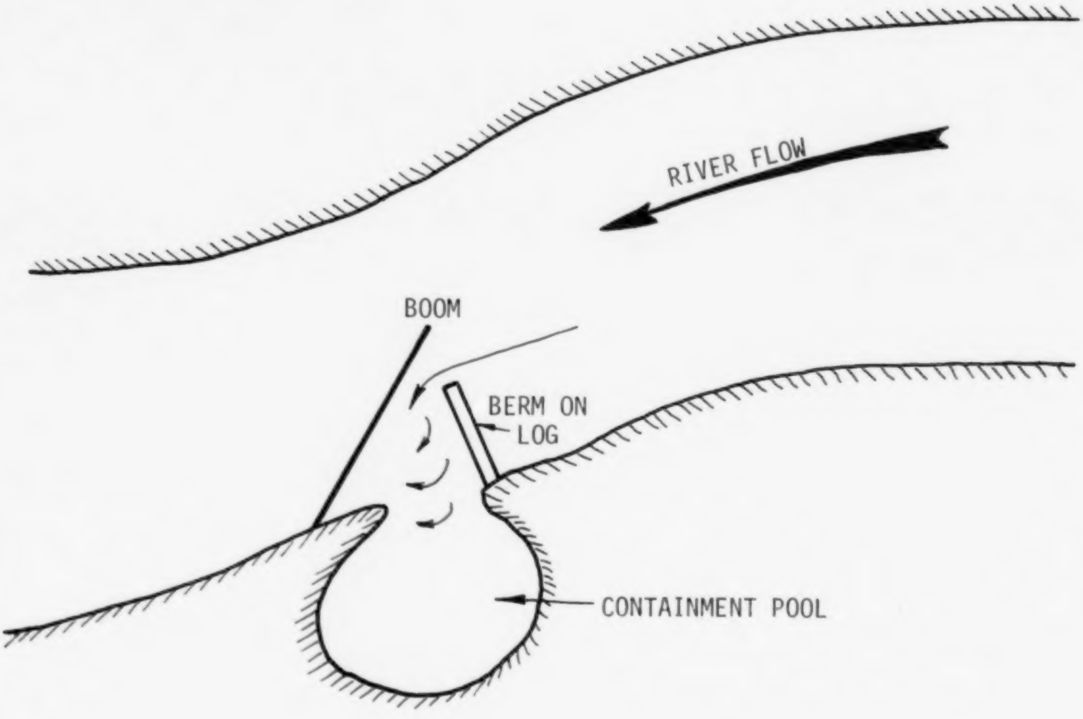
RIVER FLOW
BOOM
BERM ON LOG
CONTAINMENT POOL

Figure 54. Riverbank collection pool.

seemed to indicate that the removal of heavily oiled vegetation and trees would be beneficial and would result in a lower level of impact than leaving them in place. These arguments are offered because it is recognized that every reader will not accept the proposed spill response methods as the best solution to the cleanup problem.

Site restoration for Response Level III consists first of cutting and burning the oiled vegetation. Next the entire area would be inspected to identify areas where vegetation is so badly damaged that erosion or thermokarst alterations may occur. These severely damaged areas would be seeded and fertilized to restore growth more rapidly.

PIPELINE SCENARIO RESPONSE COSTS

Table 46 shows the cost breakdown for the three spill response levels for the pipeline spill scenario. The paragraphs that follow comment briefly on the significant response procedures that contribute to these costs.

Cost of Response Level I

As soon as the heavy equipment is in place, the first order of business is to divert the stream to protect the spill area. This is performed by a CAT-450 with a scraper blade, and a CAT-350 rigged as a front-end loader. These vehicles would be used in the river to build the berm.

While the berm is being constructed, a third CAT rigged as a backhoe would be digging a bell hole around the area of the spill to begin repair of the pipeline. Cleaning the oiled shoreline would begin as soon as the work crews and equipment were in place. Recovery of the oil in the bell hole and the oil leaching into the river is an important part of Response Level I, and this effort continues as long as the spill response crews are in place. That is, cleaning at the spill site continues through Response Levels II and III. The complete effort is expected to take about 24 days, but since there is a fairly large volume of oil remaining at the spill site at the end of 24 days, some lower level of effort would probably be required at the spill site for a much longer period of time. Skimmers would be required at the water's edge as long as leaching continued into the river; however, this analysis stops when Response Level III is completed.

After the berm and bell hole have been constructed, the heavy equipment would then be used at the disposal site to process the oiled sand and gravel being transported in from the shoreline. Oil recovered from the water would also be taken to the disposal site and burned with the oiled sand or used on the haul road for dust control.

Cost of Response Level II

The principal costs for Response Level II are for the personnel in the work crews and the helo to provide the logistic support. The tasks described for Response Level II occur over a relatively short period of time; each of the three tasks take only one day. The success of this phase of response

TABLE 46. PIPELINE SPILL COST SUMMARY

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
I.	*Equipment*			
• Divert Stream Around Spill Area	Cat-450	1	15	1,755
	Cat-350, FEL	1	1	117
• Clean Spill Site	Cat-350, Backhoe	1	3	351
	4 Wheel Drive Trucks	2	4	600
• Clean Heavily Oiled Beach	Centrifugal Pumps	2	24	3,480
	65 BBL Vacuum Trucks	2	24	24,176
	Manta Ray	1	24	1,080
	Bladder Tanks	3	24	4,560
	Komara Mini-Skimmers	1	24	10,800
	CSI Mop Skimmer	1	24	11,040
	Containment Boom	1,000 ft	24	36,000
	Hand Tools	-	11	3,696
	Plastic Bags	6,450	--	1,287
	Equipment Operation	-	11	3,394
				102,336
	Personnel			
	Spill Control Specialist	1	15	8,100
	Supervisor	1	15	8,100
	Foreman	2	15	12,240
	Equipment Crews	6	15	43,200
	Truck Drivers	4	15	17,760
	Skimmer Operators	2	24	14,208
	6-Man Crews (8 ea)	48	11	143,616
	Equipment Maintenance	2	15	10,560
	Medical	2	15	8,880
	Cook	4	15	17,760
	Logistics	4	15	16,320
		76		300,744
	Support			
	Consumables	-	26	68,145
	Shelters	15	--	42,000*
	Personnel Transport	50	--	6,750
	Helicopter	400 hrs	15	24,000
	Communications Shelter	1	15	4,800
	Equipment Transport	-	--	2,325
				148,020
Site Restoration	Leave unrecovered oil to degrade naturally.			
Total Response Level I				551,100

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* Purchased.

Continued.

TABLE 46 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
II.	*Equipment*			
• Clean Lightly Oiled Beach Downstream • Recover Oiled Logs and Debris • Recover Oil From Slack Water Areas	Cat-450	1	2	234
	4 Wheel Drive Trucks	2	1	150
	Hand Tools	-	2	340
	Morris MI-2 Skimmer	6	1	300
	Helo	-	-	12,800
				13,824
	Personnel			
	Spill Control Specialist	1	3	1,620
	Supervisor	1	3	1,620
	Foreman	2	3	2,448
	Equipment Crews	2	3	2,880
	Truck Drivers	4	3	3,552
	6 Man Crews (4 ea)	24	-	19,584
	Equipment Maintenance	1	3	1,056
	Medical	2	3	1,776
	Cook	3	3	2,664
	Logistics	3	3	2,448
		43		39,648
	Support			
	Consumables	-	3	9,285
	Shelters	-	-	(1)
	Communications Shelter	1	3	960
				10,245
Site Restoration	Unrecovered oil left to degrade naturally.			
Total Response Level II				63,717

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(1) Purchased.

Continued.

TABLE 46 (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
III				
• Recover Oil Spilled in River	*Equipment*			
	Containment Boom	-	2	3,000
• Polish Beach	Morris MI-2 Skimmers	4	2	400
	Sorbents	-	2	7,686
• Remove Oiled Vegetation	Hand Tools	-	4	672
	Chain Saws	8	2	240
	Helo	-	6	19,200
				31,198
	Personnel			
	Same as Response Level II	43	6	79,296
	Support			
	Consumables	-	6	18,570
	Shelters	-	-	(1)
	Communications Shelter	-	6	1,920
				20,490
Site Restoration				8,000
Total Response Level III				138,984

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(1) Purchased.

Continued.

TABLE 46 (continued).

COST TO BREAK CAMP

Costs remain the same for all Response Levels.

Transportation

Personnel	$ 6,750	
Equipment	3,325	
		$ 10,075
Labor to Break Camp		9,600
Total Cost to Break Camp		$ 19,675

would depend to a large extent on the ability of the helo to transport the crews to the more distant areas and haul the oiled sand and gravel out. Recovering the oiled logs and debris would be a major undertaking for the helicopter. This would require a helicopter with a high lift capability, and would also involve a large commitment of flight time.

Response Level II also includes deploying men by helo to skim oil pooled in slack water areas. This polishing effort would be limited to one day. The success of the operation would depend on the accessibility of the oil and the amount that had actually settled in slack water areas. Only a small amount of oil is expected to be recovered in this way, probably less than a barrel. Crews deployed for skimming will use the Morris MI-2 portable disc skimmer and collect the oil in a barrel. These devices are already in place from previous response levels.

Site restoration for this response level includes removal of the oiled trees and vegetation. The unrecovered oil will be left to degrade naturally.

Cost of Response Level III

Response Level III suggests the deployment of containment boom to skim oil off the river. The success of this effort would depend to a large extent on local conditions. As mentioned previously, use of booms on the Koyukuk River would probably only be successful in areas where the water velocity is lower than normal and where oil may naturally pool in slack water areas. The boom selected for use should be light weight, easy to handle, and have good containment characteristics in fast water. Some of the booms shown on Table 31 meet most of these requirements. The booms rated as average would be best, and of these, the Acme is possibly the best selection because of its light weight, compactability, and its characteristics in fast currents.

Sorbents are one of the larger costs for Response Level III. The cost shown on Table 46 includes the cost of the sorbent materials plus the cost of mops, wringers, and collection barrels.

Site restoration consists of cutting and burning the oiled vegetation; however, after the response effort had been completed, the area would be inspected from a helicopter to find areas where vegetation is so badly damaged that erosion or thermokarst alterations may occur. These severely damaged areas would be seeded and fertilized to restore growth more rapidly.

ENVIRONMENTAL IMPACT OF THE PIPELINE SPILL

The basic method of determining environmental impact and response effectiveness was described in the writeup on the blowout scenario; however, the characteristics of the pipeline spill result in some changes in the details of the computations. The specific procedures used for the pipeline spill analysis are therefore described in the paragraphs that follow.

Table 47 shows the steps that were followed in determining spill impact and spill response effectiveness for the pipeline scenario. Mathematical subscript notation is used because the contents of each space must be identified for the description of the analysis. This discussion supplements the brief description contained on Table 47.

The analysis begins by determining the spill area, volume, and environmental sensitivity over time to show the impact if no response action were taken. The time periods used can be any that seem to be convenient for analysis of the response actions planned. For a large open water spill, the times selected may be a period of months, while for a very small spill the times may only cover a day or two. In this analysis it is convenient to use the period of time required to complete each response action, which happens to be 15, 18, and 24 days. Unfortunately, these periods of time cannot be determined until the response actions are fully planned, therefore plotting the spill behavior is an iterative process. That is, the general spill behavior must be determined in order to plan the spill response actions, then the specific condition of the spill must be determined at the time each response action is completed.

In the pipeline spill response scenario, each response level is accomplished in addition to, and following, the one that preceded it. As a result, there are some blank spaces in the analysis chart. If the scenario had involved an open water spill in which each response level consisted of a selected percent recovery, action to complete each response level, or percent recovery, would have commenced at time zero and continue until the response effort was completed. In this case, all of the spaces would be filled because each response level is a continuous process and not an add-on to the previous level.

The procedure described in this chart gives the analyst a wide range of flexibility because the system can account for the spill increasing or spreading with time, and also evaporating or being recovered. Although A and V can increase or decrease for any response level (any row), all A's and V's must be greater than or equal to the value immediately below it. This simply means that even though the spill may be spreading with time, at any specific time a spill response action has either reduced the size of the spill, or at worst, the spill has remained the same. Using this method, the size of the spill can be increasing faster than the spill is being recovered, but a response effectiveness can still be determined because the spill is smaller than it would have been if no response action had been taken.

The sensitivity of the environment to the spill, shown by S, can increase or decrease in any direction. In an open water spill, S can be expected to increase as the spill spreads and decrease as the spill is recovered. For an inland spill, the behavior of the sensitivity may be more irregular. The sensitivity may generally decrease as the oil is recovered; however, some spill response efforts that involve intensive use of manpower or heavy equipment may be more damaging to the environment than leaving the oil in place. In this case, S may increase for the higher levels of response. Ordinarily these kinds of actions will not be taken, but sometimes there is

TABLE 47. SPILL RESPONSE EFFECTIVENESS COMPUTATION METHOD

Time – Days Response Level	0(1)	15(2)	18(3)	24(4)	$I = \Sigma A \cdot V \cdot S$	Response Effectiveness
0	$A_{01} \cdot V_{01} \cdot S_{01}$	$A_{02} \cdot V_{02} \cdot S_{02}$	$A_{03} \cdot V_{03} \cdot S_{03}$	$A_{04} \cdot V_{04} \cdot S_{04}$	I_0	
I	↓	$A_{12} \cdot V_{12} \cdot S_{12}$	$A_{13} \cdot V_{13} \cdot S_{13}$	$A_{14} \cdot V_{14} \cdot S_{14}$	I_1	$1 - \frac{I_1}{I_0}$
II	↓	↓	$A_{23} \cdot V_{23} \cdot S_{23}$	$A_{24} \cdot V_{24} \cdot S_{24}$	I_2	$1 - \frac{I_2}{I_0}$
III	↓	↓	↓	$A_{34} \cdot V_{34} \cdot S_{34}$	I_3	$1 - \frac{I_3}{I_0}$

Rules for Determining Response Effectiveness

Determine spill impact for the 0 level response $\left(\sum_{i=1}^{4} A_{0i} \cdot V_{0i} \cdot S_{0i} \text{ or } I_0 \right)$. Next determine impact for the time required to complete the spill response levels selected, in this case, 15, 18, and 24 days. For this scenario, each Response Level adds on to the previous level, therefore some spaces on the chart are vacant. For each vacant space, the value vertically above is substituted.

A and V can increase or decrease in any horizontal row. Increasing values show that more oil is being spilled or that the spill is spreading; decreasing values show that the spill is evaporating or being recovered. Response Level 0 always has the maximum value for A or V for any vertical column. All A and V must be $\leq$ the value immediately above.

S may increase or decrease in any direction. S is expected to decrease unless a spill response procedure has an adverse impact on the environment.

a question about the impact of the response effort itself, then an evaluation of this impact is useful. This is one of the benefits of this kind of analysis; it will tend to show the cases in which the response effort has an adverse impact.

The last two columns of the chart show that the spill impact is the sum of the products of A, V, and S, and the response effectiveness is a comparison of the impact after each response action has been taken to the impact if no response action had been taken.

Computing spill response effectiveness is a useful analytical tool, but it does not result in firm, absolute values. For example, the area covered by the spill is a good indicator of environmental impact; however, if the spill is rapidly spreading out to a sheen, the area may be so large that it may no longer be causing a higher level of impact but rather a lower level because the film is so thin. This is a special situation in which some other method of analysis may be required.

Another problem with this method of analysis involves the use of the spill sensitivity factors. Although these values are selected with a considerable amount of care, they are based on a judgement. In this study the sensitivity factors range over a scale of 0 to 4, with 0 being the least severe impact and 4 being the most severe impact. The scale might also have been set to a range of 1 to 10, or even 1 to 100. These changes, of course, would have an important effect on the results, or at least how the results are interpreted. This situation is unfortunate, but it should not detract significantly from the usefulness of the results. The usefulness of the results depends on the consistency of the analysis, so that the consequences of different spill response actions can be compared. Using a single set of sensitivity factors for the analysis provides this consistency, and therefore the result makes a valuable contribution to determining spill response effectiveness. It is possible that the range of the sensitivity values could be adjusted at the start of the analysis to make the results consistent in the range of values of A and V that are expected; however, changing the range of sensitivity values to suit every situation may also lead to adjusting numbers to get the desired result. It suffices to say that using a range of values for sensitivity of 0 to 4 tends to minimize environmental sensitivity in cases where spill volumes and areas are large. For large spills, the range of the sensitivity probably should also be large, but the analyst must avoid the temptation of "playing with numbers" to show what seems to be the most desirable result.

Table 47 shows the way in which the analysis was performed for the pipeline scenario, but the analysis itself was far more complicated because of the level of detail that is required to describe a complicated oil spill problem. Unlike an open water spill, the oil was not in a single environment. Areas, volumes, and impact was therefore computed separately for the spill site, the shoreline downstream that was coated after the flood waters subsided, and the oil that was transported in the river. In addition, after breakup the oil from the spill site continued to leach out into the river. Some of this oil coated the shoreline farther downstream and some coated trees and vegetation along the shoreline. Since the leaching process is gradual, volumes of oil remaining, leaching, and evaporating were computed for the time of completion of each response level. Without further explanation the reader will understand that the simple computational table must be supported by an elaborate system of accounting of where the oil is at any particular time. This system must follow oil leaving one area for another, and show how much is evaporating or is being recovered and therefore is not available for recovery farther downstream. This task can be, and was, performed by hand, however most problems of even a moderate level of complexity would be best solved using a digital computer.

Table 48 shows the spill sensitivity of each environmental factor for the pipeline spill scenario. As before, the impact is evaluated for each level of response on a scale of 0 to 4. These numbers are then combined with the volume of the spill and the area covered by the spill to determine spill response effectiveness.

PIPELINE SPILL RESPONSE EFFECTIVENESS

The spill response effectiveness following the pipeline spill is a function of the area covered by the spill, the volume of oil remaining on the ground, and the sensitivity of the various environmental factors to this volume of oil. Because of the complexity of the pipeline spill, determining spill response effectiveness involves a long series of computations. Only a summary of the results of these computations will be reviewed here.

Volume of oil Recovered During Each Response Level

The following paragraphs show the volumes of oil that were assumed to be recovered at various locations for each response level. These figures do not account for every volume of oil that was used in the computation of spill response effectiveness, but they do provide the reader with a picture of where the oil was, and where it was recovered.

The volume of oil available for recovery is initially in three locations:

- At the spill site
- On the river bank downstream
- On the river.

As the oil continues to leach out of the ground at the spill site, it is expected to coat the river bank downstream of the area that was coated by the flood waters at breakup; that is, beyond the original 16 km that was contaminated. Some of this oil will coat the river bank farther downstream (about 30%), some will coat logs and vegetation (about 10%), and the rest will remain in the river. In the data that follows, oil "downstream" refers to the heavy coating of oil deposited in the first 16 km downstream after breakup. The oil referred to as "shoreline, downstream" is the oil that is leaching from the spill site and contaminating the shoreline, vegetation, and waters of the river farther downstream.

TABLE 48

PIPELINE SPILL SENSITIVITY

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Soil Stability	
(3) As the oil is carried downstream at breakup, it coats each shoreline for about 16 km. This is mainly gravel, but significant amounts would be carried into organic soils causing permafrost degradation and bank erosion.	(4) Response would not affect amount of oil in organic soils downstream from spill. Response effort would contribute to further instability.
Permafrost	
(2) Serious degradation would occur in organic soils where oil is swept up onto the bank. Degradation of permafrost in gravel would have little effect.	(4) Same as above.
Aquatic Habitats (fresh)	
(4) High concentrations of soluble toxic elements of oil are carried downstream from the spill and into side channels. Spawning and rearing areas of grayling, chum salmon, and whitefish are seriously affected, water quality is reduced and biological productivity severely curtailed.	(4) Most toxic elements of the oil have already entered into solution in the river. Response has little effect.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Soil Stability	
(4) Response would not affect any change in oiling of organic soils.	(4) Same as II at left.
Permafrost	
(4) Same as above.	(4) Same as above.
Aquatic Habitats (fresh)	
(4) Same as above.	(4) Same as above.

(Continued)

TABLE 48 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Wetland Habitats	
(4) Wetlands in the floodplain throughout the 18 kilometers as far as Clam Creek would be inundated by oil and rendered totally unproductive. Farther downstream for a considerable distance, probably as far as Bettles, occasional ice jam flooding would float oil into more extensive wetland habitats. Although that oil would be more weathered, damage to those areas would also be significant.	(4) Response would have little effect on downstream wetlands.
Upland Habitats (unvegetated)	
(3) Gravel bars along the river throughout the spill area would be coated with oil and would be useless as nesting sites for shorebirds or as gravelling areas for waterfowl. Their usefulness as travel routes would be reduced.	(3) Remaining beach would still contain enough oil to render it unsuitable for nesting birds. Could be used as a travel route by mammals.
Upland Habitats (vegetated)	
(3) Habitats along the river margin would be thickly coated with oil for 16 km downstream from the spill site. Lesser amounts would inundate areas where ice jams cause local flooding during breakup. Productivity of these important streamside habitats would be reduced.	(3) No significant effect from response action.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Wetland Habitats	
(4) Response would have no significant effect on productivity of wetlands.	(4) Same as II at left.
Upland Habitats (unvegetated)	
(3) Beach would still be unsuitable for nesting birds.	(3) Same as II at left.
Upland Habitats (vegetated)	
(3) No significant effect from response action.	(3) Removal of logs and trees would have adverse effects beyond the time when the oil would have become harmless if left alone.

(Continued)

TABLE 48 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Finfish	
(4) Spawning, overwintering, feeding, and migration habitats of fish, primarily grayling, in the primary spill area would be inundated by oil and all fish present would be killed. Farther downstream (about 18 km), mortality would be reduced as concentrations of oil diminished, but the number of species affected would increase and chum salmon, northern pike, and others would be affected by toxic elements of oil and the reduced productivity of the habitat. Salmon migration, primarily of chums, into the entire Koyukuk drainage could be disrupted or delayed as tainted water entered the Yukon River from the Koyukuk system.	(4) Response action has no effect on the oil which has already escaped into the river.
Birds (water-related)	
(3) Whitefronted and Canada geese, ducks, and shorebirds migrating along the river, using its bars and nesting on its margins, would be coated with oil and killed or driven from the area by reduced productivity of aquatic and upland habitat and by the presence of oil.	(3) Damage to migrating birds significantly reduced by eliminating danger from casual contact with beach in first 16 km. Other habitats unaffected.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Finfish	
(4) Same as I at left.	(4) Same as I at left.
Birds (water-related)	
(2) Removal of oil from additional beach and slack water areas further reduced danger to migrants. Still in effect on nesting habitat.	(2) Little significant improvement over II at left.

(Continued)

TABLE 48 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Birds (non-water-related)	
(2) Reduction in productivity of upland, wetland, and aquatic habitats would reduce the productivity of the habitat for upland birds. Some would be coated with oil and a few killed. Some raptors would be contaminated by contact with oil-coated prey or carrion.	(2) Response effort woud have little effect on danger to non-water-related birds.
Mammals (water-related)	
(4) Mink, river otter, and beaver would be eliminated from the immediate area of the spill and for about 18 km downstream. Farther downstream, they would be less affected as concentrations of oil diminished.	(4) Response effort would not alleviate first effects of the spill.
Mammals (non-water-related)	
(2) Small mammals with low mobility, such as shrews, voles, snowshoe hares, and red squirrels, would be heavily contaminated in the immediate area of the spill and would suffer considerable mortality. These same species would be affected, but to a lesser degree, in upland river margin habitats downstream. Large mammals such as moose, caribou, black and grizzly bears, wolves, and wolverines would be less affected. Scavengers could suffer from contact with contaminated carrion.	(2) Response effort would have little effect. Grizzly bears would either leave the area because of disturbance or be attracted to garbage and possibly shot.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Birds (non-water-related)	
(2) Little significant effect beyond response level I.	(2) Removal of trees and logs would cause damage that would remain after oil had weathered to a harmless state.
Mammals (water-related)	
(4) Same as I at left.	(4) Same as I at left.
Mammals (non-water-related)	
(2) Response effort would have little effect. Bear problems from presence of people would remain.	(3) Removal of logs and trees would diminish attractiveness of the area to small mammals for an extended period. Bear problems from presence of people would remain.

(Continued)

TABLE 48 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Human Use of Minerals	
(2) The area has potential for extraction of minerals and placer mining has taken place. Activity is probably increasing with the rise in the price of gold. Most mining is above the river floodplain elevation, but that which is on the floodplain would be severely affected within the primary spill area and moderately affected for 18 km downstream.	(2) Little effect from response effort.
Human Domestic Use of Water	
(2) Water in the river would be tainted for many miles downstream from the spill. It would probably be otherwise safe for drinking.	(2) Little significant effect from response.
Human Use of Vegetation	
(1) Some gathering of logs for construction and firewood from the floodplain by miners and others would be affected near the spill area where oil inundated spruce stands.	(1) Little effect from response effort.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Human Use of Minerals	
(2) Same as I at left.	(2) Removal of trees would be a long-term, though slight, loss of construction material. Slight benefit from added cleanup.
Human Domestic Use of Water	
(1) Additional cleanup has reduced amount of oil leaching into the river.	(1) Even though cleanup has been thorough, the small amount of oil leaching into the river would taint the water.
Human Use of Vegetation	
(1) Same as I at left.	(2) Removal of heavily oiled trees would be a long-term loss of construction materials and firewood.

(Continued)

TABLE 48 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Human Use of Fish	
(4) Opportunity for sport fishing for grayling in the spill area would be destroyed. The small amounts of oil that continued downstream past Evansville, Bettles, Allakalet, Hughes, and Huslia would seriously taint all fish in the river and eliminate use of an important resource. Salmon runs in the Koyukuk system could be diverted or delayed with disastrous and long-lasting consequences to a major food resource.	(4) Response effort would not affect oil that had already flowed into the river.
Human Use of Birds	
(1) Even though there is no legal provision for taking, considerable use is made of migratory birds in spring below the spill area. There would be some tainting of birds taken.	(1) Extent of cleanup would reduce tainting of birds, but presence of cleanup crews would interfere with hunting.
Human Use of Mammals	
(1) Few mammals are taken at the time of the spill in the spill area except for grizzly bears. Bears in the spill area would be tainted and values of hides diminished. Fur animals taken the winter following the spill in areas downstream from the spill could be slightly tainted and value of fur slightly reduced. The abundance of fur animals would also be slightly reduced.	(1) Little effect from response effort. Grizzly bears unavailable during cleanup effort.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Human Use of Fish	
(4) Enough oil removal from gravel shorelines and backwaters for 32 km downstream to shorten the duration of effects. Majority of damage is already done, however.	(4) Response effort might have reduced leaching of oil into river sufficiently to eliminate effects on salmon migration. Salmon caught might be fit for food. Majority of effects are beyond area of response, however.
Human Use of Birds	
(1) Same as I at left.	(1) Same as I at left.
Human Use of Mammals	
(1) Same as I at left.	(2) Removal of logs and trees would have long-term adverse effects on availability of fur animals. Grizzly bears unavailable during cleanup.

(Continued)

TABLE 48 (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Agriculture	
(0) Oil would not inundate garden sites.	(0) Same as for No Response.
Other Community Activites and Facilities	
(1) Boats using the river below the spill area would be lightly coated by oil, as would float planes at Bettles and other downstream river areas.	(1) No effect from response
Endangered Species	
(1) Although peregrin falcons have been reported to nest in the region, the probability of their nesting close enough to the spill area to be affected is extremely low. There is some possibility that migrating birds might take contaminated prey and be slightly affected by contact with oil.	(1) No effect from response.
Aesthetic Quality	
(4) Shorelines of the river would be completely coated by oil for at least 16 km downstream from the spill and the water itself would be covered with an oily sheen for a much greater distance. "Chocolate mousse" would be extensive on debris and river margins for an extended period.	(4) Little effect from response. Some improvement in appearance of beach.
Air Quality	
(1) There would be a noticeable persistent odor of oil for a long distance downstream from the spill.	(2) Little effect from cleanup. Burning oiled gravel would create considerable smoke.

(Continued)

TABLE 48 (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Agriculture	
(0) Same as for No Response.	(0) Same as for No Response.
Other Community Activities and Facilities	
(1) Same as I at left.	(1) Same as I at left.
Endangered Species	
(1) Same as I at left.	(0) Possibility of a peregrine falcon becoming contaminated by its prey virtually eliminated.
Aesthetic Quality	
(3) Response would shorten time for recovery, but recovery would still be slow.	(4) Removal of trees would offset improvements on a long-term basis.
Air Quality	
(2) Considerable smoke from burning oiled debris.	(3) Burning of cut, oily vegetation, trees, and logs would create a widespread pall of smoke.

The figures that follow summarize the results of the calculations made to determine the volume of oil available for recovery and the volume of oil recovered for each response level. The volume of oil available for recovery at breakup includes the oil at the spill site and the oil stranded on the river bank downstream. At that particular time, the oil in the river is assumed to either be deposited along the shoreline, or gone downstream and available for recovery. The oil that leaches out of the river bank does go out into the river and is available for recovery.

For the computations, volumes of oil were expressed in cubic meters; however, the volumes in this section are shown in the more familiar units of barrels.

Response Level 0--

Oil Available for Recovery

Spill Site	7,504 BBL
Downstream	6,303 BBL
Total Available for Recovery	13,807 BBL (2,195.1 m^3)

Response Level I--

Oil Available for Recovery

Spill Site; about 38% has leached into the river	4,653 BBL
Downstream; 30% evaporates off in 11 days, then evaporation stops	4,412 BBL
Shoreline Downstream; 30% coats shoreline > 16 km downstream, 10% coats logs and vegetation, and 60% remains on the water	2,851 BBL
Total Available for Recovery	11,916 BBL (1,894.4 m^3)

Oil Recovered

From bell hole	
Day 15	300 BBL
Day 18	138 BBL
Day 24	69 BBL
Leaching into river	
Day 15	855 BBL
Day 18	76 BBL
Day 24	60 BBL
Downstream	3,309 BBL
Shoreline, Downstream (evaporation)	
From shoreline, downstream	280 BBL
Logs	93 BBL
Water Surface	560 BBL
Total Oil Recovered (or evaporated)	5,740 BBL (913 m^3)

Response Level II--

Oil Available for Recovery

Spill Site; about 45% has leached into river	3,253 BBL
Downstream	1,103 BBL
Shoreline, downstream	246 BBL
Logs and vegetation	82 BBL
On the water	491 BBL
Total Available for Recovery	5,175 BBL (822.7 m^3)

Oil Recovered

Shoreline downstream	25 BBL
Logs and vegetation	8 BBL
Water surface	7 BBL
Total Oil Recovered	40 BBL (6.3 m^3)

Response Level III--

Oil Available for Recovery

Spill Site; about 60% has leached into river and some has been recovered	2,105 BBL
Downstream	1,103 BBL
Shoreline, downstream	172 BBL
Logs and vegetation	57 BBL
On the water	344 BBL
Total Oil Recovered	3,781 BBL (601.2 m^3)

Oil Recovered

Downstream	110 BBL
Shoreline, downstream	17 BBL
Logs and vegetation	6 BBL
Water surface	35 BBL
Total Oil Recovered	168 BBL (26.6 m^3)

Pipeline Spill Response Effectiveness Computation

Spill response effectiveness is determined by computing the spill impact, which is the product of the volume, area, and sensitivity, and comparing this impact to the impact with no spill response. Table 47 shows the details of the method used in making these calculations. Spill sensitivities are taken from the list of pipeline spill sensitivities in Table 48. Notice that Table 48 gives the sensitivities according to specific targets of spill impact such as permafrost, aquatic habitats, human use of birds, and so forth. To perform the computations for effectiveness analysis, the sensitivities must be applied to specific locations where spill areas and volumes are changing, such as the spill site, the shoreline downstream, and the river. To make these computations, spill sensitivities are averaged according to type. The types, or classes, of sensitivity factors are given in Table 41. For the pipeline spill scenario, the average of the spill sensitivity for physical factors and human factors is applied to the spill site and to the area downstream; the average of the biological factors is applied to the river. Table 49 shows the pipeline spill impact and response effectiveness.

TABLE 49 PIPELINE SPILL IMPACT AND RESPONSE EFFECTIVENESS

Response Level	0	I	II	III
Impact (m^5)	$5.697 \cdot 10^9$	$3.529 \cdot 10^9$	$3.387 \cdot 10^9$	$3.505 \cdot 10^9$
Response Effectiveness	--	0.381	0.405	0.385

The spill response effectiveness shown in Table 49 is not particularly high but it can be considered to be realistic. Figure 55 shows this same result plotted on a graph. Note that the values for response effectiveness are very nearly equal, and that the effectiveness for Response Level III is even lower than the value for Response Level II. An explanation of how these results occurred will provide additional insight into the response problems involved in the pipeline spill scenario.

First, consider the reasons why the effectiveness of Response Level I is high in comparison to that for Levels II and III. A major part of Response Level I involves the recovery of oil at the spill site; that is, oil in the bell hole where the pipeline is being repaired and oil is leaching into the river at the spill site. Further, the recovery operation at the spill site continues for the entire duration of the response action. Since a large volume of oil is available at the spill site and the recovery operation continues for a long period of time, a large volume of oil is collected, which contributes to a high level of response effectiveness.

Spill response effectiveness in Response Level I has also been enhanced because cleaning the heavily oiled beach has been included as part of this response level. This rather sizable collection effort is expected to result in recovery of a large volume of oil, which also helps to make the effectiveness of Response Level I high. For the purposes of this analysis, it would have been convenient to include the beach cleaning operation in Response Level II rather than Response Level I. This would have provided the analyst with a gentle upward slope for the curve in Figure 55 showing Response Level II to be about twice as effective as Response Level I. This might have made a better analysis but it would not have made much sense for the real spill response requirements that exist in Alaska. A heavily oiled shoreline on a sensitive stream will not be left to degrade naturally with no spill collection effort. This has already been shown from the pipeline spills that have occurred. In this case, then, a smooth analysis has been sacrificed to make the spill response levels more typical of real world conditions. On the other hand, by this reasoning the analysis is shown to

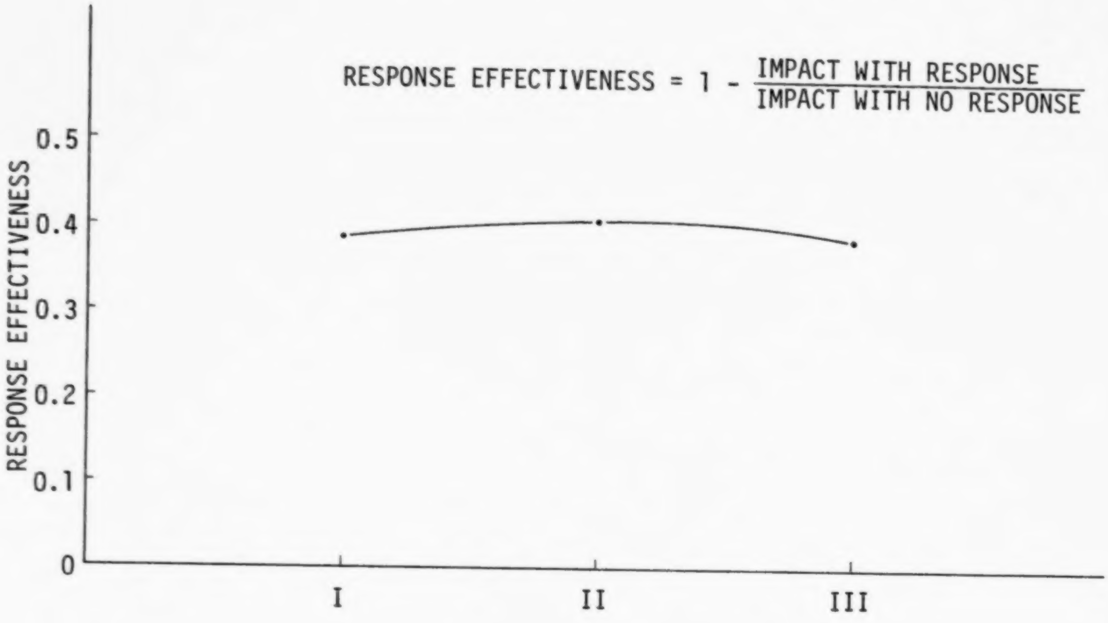

Figure 55. Pipeline spill response effectiveness vs. spill response level.

provide additional insight into the spill response problem. That is, leaving the oil on the shoreline in place, or leaving this part of the response effort until last, should be considered as a possible response alternative.

By including the beach cleaning effort in Response Level I, the return for Response Level II remains fairly small and the spill response effectiveness changes very little over Response Level I. This result can be expected and is very likely representative of real world conditions. Also recall that the response levels are cumulative. Response Level II is performed in addition to Response Level I; therefore, since Response Level II only accounts for a small amount of recovered oil, the effectiveness level is high, but only slightly higher than that for Response Level I.

Finally, Figure 55 shows that spill response effectiveness for Response Level III is lower than that for Response Level II. The first comment one may make is that the difference is small and well within normal differences that could be expected in making the many computations required to determine response effectiveness. Although this is true, the drop in response effectiveness does not have to be dismissed so lightly. There are other reasons for this difference that are instructive in understanding the impact of the spill response effort itself.

Table 47 shows how spill response effectiveness is computed. Recall that the rule for using the procedure requires that the area and volume in each column must be less than or equal to the value directly above it. Using this rule, there is no way that response effectiveness can drop based on area and volume alone. This brings us to the third factor in the product used for spill impact, sensitivity. The spill sensitivity is expected to decrease with each response level, but it is not constrained to do this. In fact, intensive efforts to recover the last small amount of oil for an inland spill are likely to be more destructive to the environment than leaving the oil in place. This is what happened in Response Level III. The spill sensitivities for the various response levels tend to remain the same, and even increase in some cases, for the higher levels of response. When the sensitivities remain the same, it may be that the oil spill impact is replaced by an impact caused by the response crews and heavy equipment. In cases in which intensive efforts are mounted on land to collect small amounts of oil, the sensitivity to the response effort may be considerably greater than the sensitivity to the spill. This is what happened in Response Level III of the pipeline scenario. The fact that the response effectiveness for Response Level III is only slightly less than that for Level II can be accounted for by noting that the sensitivities used in the computations are an average of a great many sensitivity factors, and therefore a few higher sensitivities for Response Level III do not change the result much. In addition, the range of values used for the sensitivities is small, 0 to 4, so that the difference that results from using a higher sensitivity is also small. If the range of sensitivities had been 0 to 10 instead of 0 to 4, and if some factor had been evaluated as highly sensitive to the collection effort in Response Level III, then the resulting decrease in response effectiveness would have been much more dramatic.

COST EFFECTIVENESS OF PIPELINE SPILL RESPONSE

As before, the cost effectiveness is defined as the quotient of normalized cost and response effectiveness. Figure 56 shows the cost effectiveness for the three pipeline spill response levels. Since the curve has no minimum, Response Level I, which gives the lowest value, is the most cost effective solution. Response Level II is only slightly more costly, and also only slightly more effective. Response Level II, therefore, represents an essentially neutral position; it may be worth the effort, but only marginally. If the effectiveness of Response Level II were slightly better it would be the most desirable solution. Response Level III is the least desirable solution. The curve shows that it has a high level of cost for the additional level of effectiveness.

Figure 57 shows the results of the response efforts in terms of the volume of oil recovered. These results do not include the influence of spill impact or sensitivity, but they do tend to emphasize the differences between the three response levels. Figure 58 shows the incremental cost per barrel of oil recovered for each spill response level. This curve is nearly the reverse of Figure 57, showing a high cost of collecting a small volume of oil for Response Level II.

Summary of the Pipeline Spill Effectiveness Analysis

As in the analysis of the blowout scenario, the pipeline scenario analysis shows that the basic level of response is the most cost effective. Cleaning lightly oiled areas at a greater distance from the spill site, which is essentially the program for Response Level II, provided only a marginal level of return. Response Level III provides for a more intensive cleaning of the shoreline downstream, which may be at least marginally effective, and also more intensive efforts to recover oil from the water surface and from the oiled vegetation. These last two efforts produce a small amount of recovered oil plus a moderate amount of damage to the environment in the collection process. The result is that the overall effect of Response Level III is adverse. As for the blowout scenario, this analysis shows that the final, intensive response measures added for Response Level III may be counterproductive.

R&D INITIATIVES SUGGESTED BY THE PIPELINE SPILL SCENARIO

Response Levels I and II call for deploying a containment boom in the Koyukuk River to collect oil on the surface of the water. The problem of containing oil with booms in Alaskan waters is tremendous. Rivers are swift, sometimes 2 to 4 knots, rocky, contain large amounts of debris such as tree stumps and heavy loads of particulates so that the oil may be hard to see. In spite of these problems, it is sometimes desirable to deploy booms to collect oil. Several courses of action are available to improve this situation:

- Test existing booms to determine which is the best suited for use in high current, shallow stream situations.

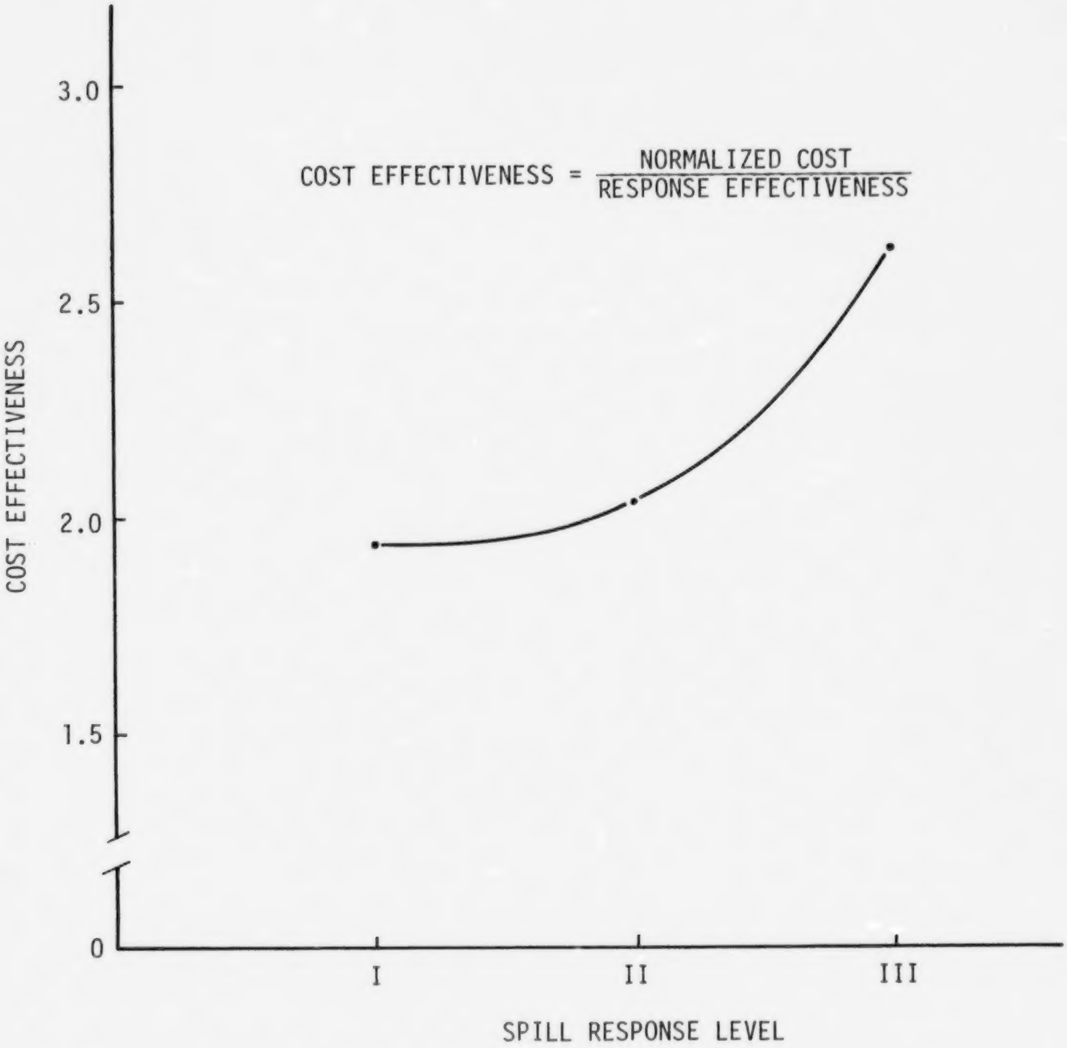

Figure 56. Pipeline spill cost effectiveness vs spill response level.

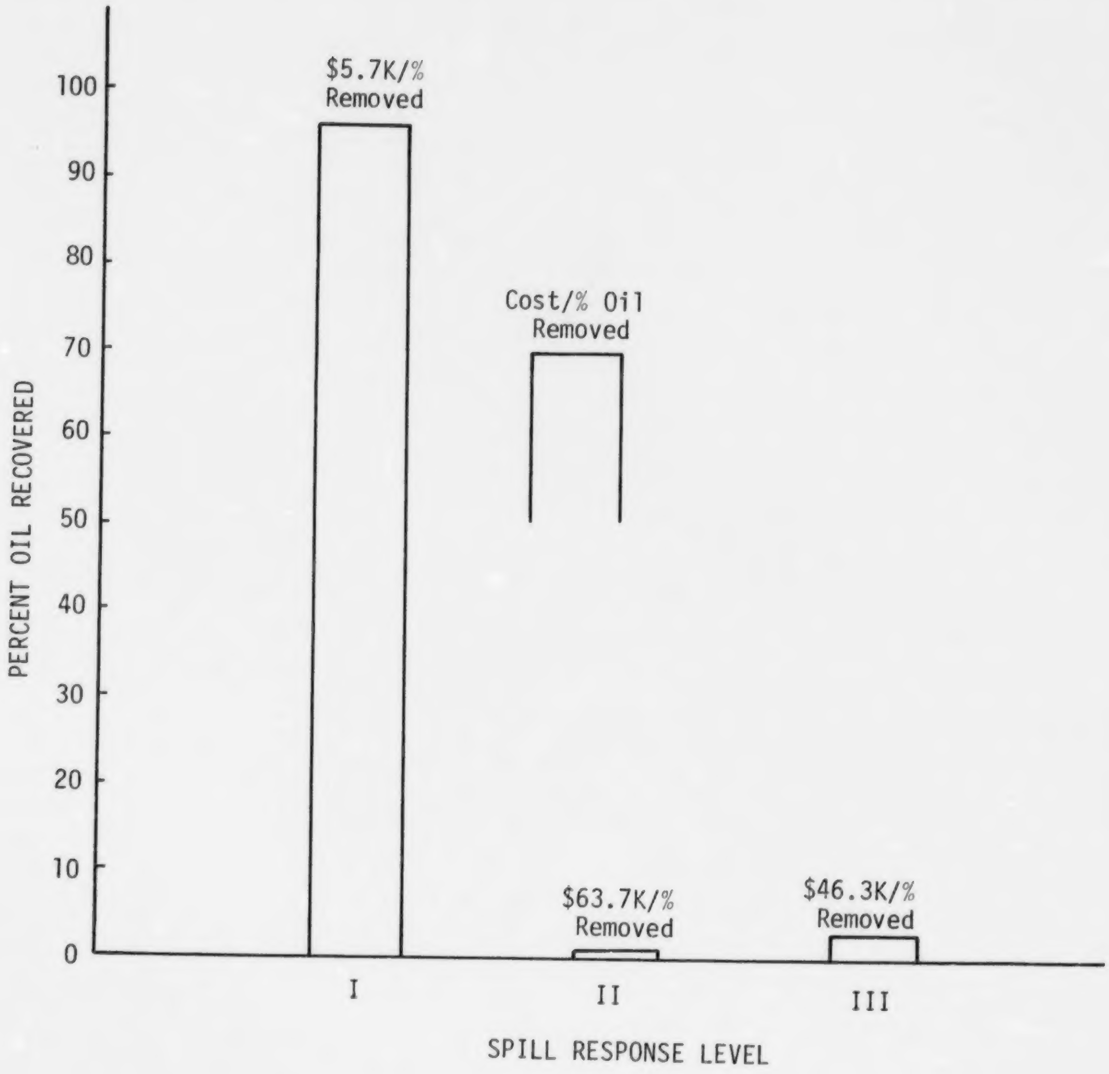

Figure 57. Pipeline percent oil removed vs spill response level for the pipeline spill.

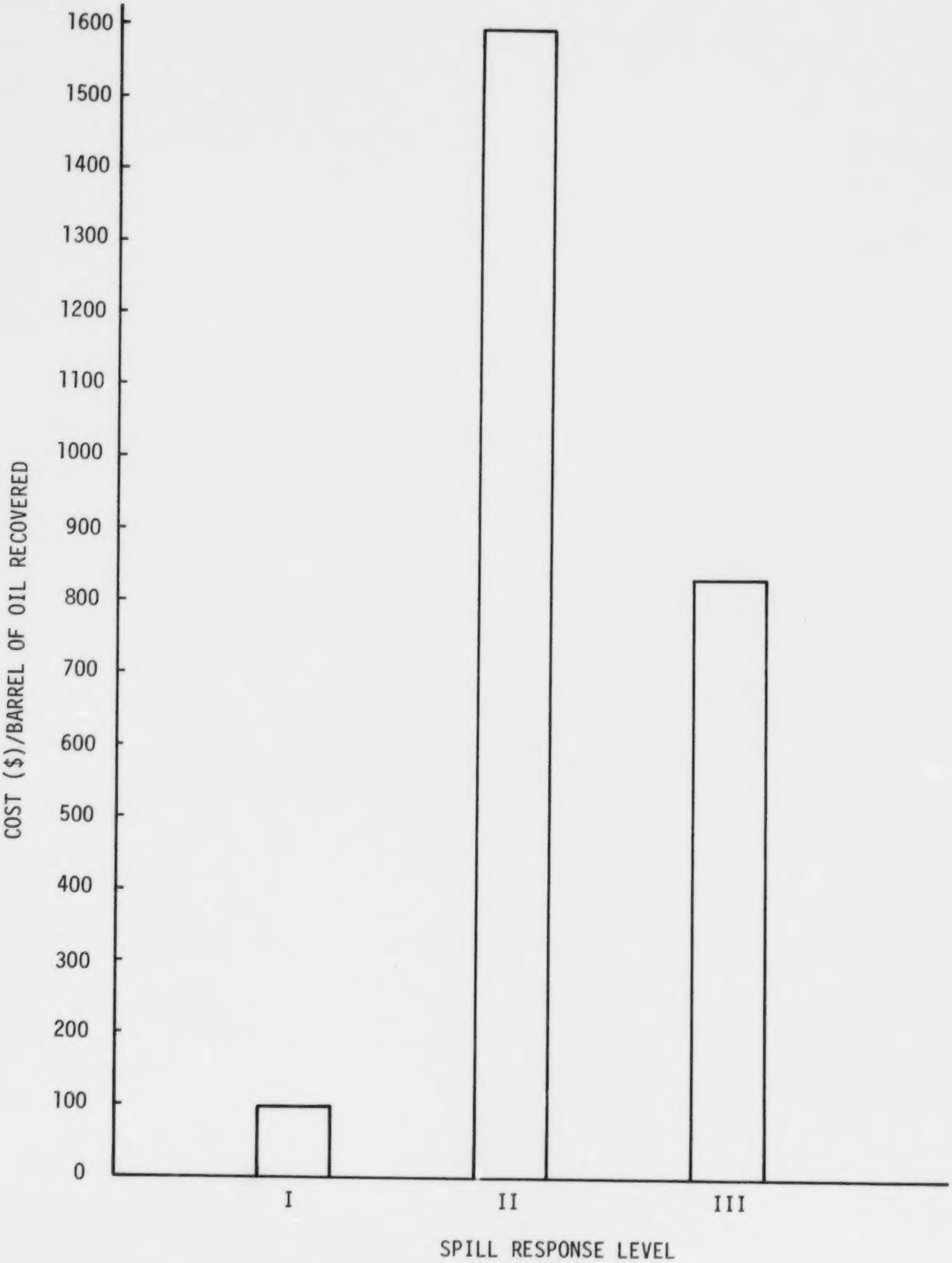

Figure 58. Pipeline cost/barrel of oil recovered vs spill response level. (Cost and barrels collected are for each response level rather than cumulative.)

- Use a hydraulic model to determine the best ways to deploy booms in these situations.

- If none of the booms available are suitable for this application, design a new boom.

Response Level I also involves the removal of the heavily oiled shoreline for cleaning. Instead of removing the shoreline, it would be better to have a device that could be used in place so that the oiled sand and gravel could be restored in its original location. A portable, diesel-fired incinerator might be suitable for this application; however, a number of other types of devices or methods for cleaning the shoreline should also be investigated. The problem of cleaning an oiled shoreline occurs in a great many spill situations. Developing a portable device to clean oiled shoreline should be a top priority R&D project.

Response Level II

Response Level II requires a light weight recovery device for picking up oil in remote inland areas. The device should be effective in fast currents, when used on thin slicks, and when used on a variety of petroleum products. Many recovery devices are available, but many do not meet the requirements of portability and ruggedness for use in remote locations. Also, many of the devices available have not been tested for use in inland locations, particularly in fast water and on thin slicks. Tests should be performed to determine if any existing devices meet these requirements. If the results are negative, a new device should be developed.

There is wide disagreement about the kinds of actions that should be taken for site restoration. Because of these differences in opinion, a number of important questions should be answered:

- Is the removal of a heavily oiled beach more damaging than leaving it in place? If so, in what cases?

- Should oiled debris, such as logs and driftwood, be collected and burned? If so, in what circumstances?

- Should oiled vegetation, including trees, be cut for disposal or burning?

- What site restoration actions are suitable for wetlands along Alaskan rivers?

- Should shorelines be altered to collect oil that would otherwise continue downstream?

Decisions concerning action to take for site restoration must be made on a case-by-case basis; however, it appears that there are no generally accepted criteria for making these decisions. Acceptable methods for site restoration should be identified and described. These methods should be accepted and approved by the responsible state and federal authorities. The accepted methods of site restoration could then be used for on-site decision making by spill response crews.

Response Level III

The analysis of Response Level III shows that the final intensive effort to recover the last small amount of oil is not cost effective and may, in fact, be more damaging to the environment than leaving the oil in place. This kind of situation is well known to nearly everyone familiar with oil spill response operations, but the analysis tends to highlight, or perhaps prove, that the condition exists using numerical indices. The law requires that even the thinnest sheen of oil must be collected and removed. Although this may be considered as a proper goal for spill response, over-zealous enforcement of this law can not only put an unreasonable economic burden on the spillor, it can also have an unusually high adverse impact on the environment. This is particularly true when the response effort occurs on sensitive shorelines, wetlands, or in other special areas such as those containing arctic tundra and permafrost.

One may reasonably ask how this situation can be corrected. A judgement must be made before a damaging spill response action is taken and there appears to be no criteria for making that judgement. It is therefore proposed that the needed decision criteria be developed based on a data base that shows the expected result of spill response actions in various situations. This data base would include the results of actual spill situations plus the analyzed results of spill simulation modeling.

Here is how it would work. Typical spill situations in sensitive environmental conditions would be identified and described using reports of actual spill incidents. These typical situations would be used to develop a spill simulation model. This model would be developed along the lines of the scenarios used in this study. The scenarios in this study are spill simulation models except that the analysis was performed by hand for a single spill situation. The proposed models would be computer-based Monte Carlo simulations using the methods of determining spill sensitivity and impact that were employed in this study. The computer simulation would have several advantages over a single-solution analysis performed by hand. First, the computer solution could be performed much faster. As a result, the analyst would not be limited to a single solution in examining the problem. The computer could be used to determine the expected results for many spill sizes, types of products, and environmental conditions. In order to review the range of input parameters in a systematic way, a Monte Carlo model would be used that would randomly select input values from a normal distribution designed for the individual spill problem. Since the solution can be developed quickly on the computer, the simulation would be run for about 100 iterations which would cause the problem solution to converge on an average, or typical result. This would provide a data base that is statistically significant over a wide range of typical conditions. These analytical results could be used to develop meaningful criteria for use by spill response officials in predicting the spill response actions that would be most effective in typical spill situations. This knowledge would decrease the excessive funding sometimes directed toward recovering an insignificant amount of the spill, and would help to prevent intensive response actions that may be more damaging to the environment than the spill itself.

FUEL FARM SCENARIO RESPONSE METHODS

The Fuel Farm Spill Response Problem

The fuel farm spill begins with the discovery of a sheen on the Kuskokwim River that is traced to a spill that has accumulated under the fuel pits at the city airport. The immediate impact of the spill is contaminated water supplies in several homes in the city. Spill response, therefore, emphasizes the removal of the primary source of the spill and the health hazard.

Response to this spill is difficult because the size of the spill is not known and may remain unknown throughout the response effort. The extent of the spill must be determined by drilling holes to map the part of the water table that is contaminated. This procedure is slow and may not give an accurate picture of the extent of the spill when completed. Collecting the oil from the water table may also be a slow process. Further, completely removing all of the spilled product from the water table is likely to be difficult because the table is likely to change seasonally. Some of the spilled product may be trapped, and therefore will not be available for recovery in the summer when the spill response effort is in progress. The effort to remove the product from the water table must be thorough, however, because the odor and taste of oil will remain even if only traces of product have not been recovered.

It will be desirable to recover as much of the spill that is leaching into the river as possible, even though, in this case, the oil in the river presents a less severe environmental hazard. The spill response effort, therefore, concentrates on recovery of the oil on the water table, with a secondary effort to recover as much of the oil leaching into the river as possible. The paragraphs that follow describe the specific spill response actions that are planned for the fuel farm spill scenario.

Fuel Farm Spill Response Methods

Table 50 summarizes the spill response methods that are proposed for the fuel farm spill. These response methods were developed in consultation with government spill response officials in Alaska, and Alaskan spill response contractors. The paragraphs that follow provide additional details concerning these response methods.

Response Level I--

Response Level I is concerned with recovering the oil from the water table. The problems involved in this response action include gaining access to the spilled oil and developing an effective way of collecting it. Table 32 lists a recovery device called the Scavenger that is especially designed

TABLE 50. FUEL FARM SPILL RESPONSE METHODS

	RESPONSE ACTION
RESPONSE LEVEL I	
• Recover Oil From Water Table	• Drill holes in spill area to map the extent of the spill. • Dig a trench at a low area in the water table where spill appears to be collecting; flush vertical column of soil flushing product into trench. • Recover oil from trench. • Find and repair leak in underground fuel line. Flush vertical column of soil and collect product in pit.
RESPONSE LEVEL II	
Level I Plus - • Recover Product Leaching Into River	• Dig several catch basins in area where product is leaching into river. Recover product with sorbents.
RESPONSE LEVEL III	
Level I and II Plus - • Recover Oil From River	• Use aircraft surveillance to identify accumulations of product in slack water or abandon meanders. Boat crew moves out to recover oil. • Deploy a boom adjacent to the location where the product is leaching into the river. Dig a small collection pool at the shoreward end of the boom.
RESPONSE LEVEL III	SITE RESTORATION
	• Chlorinate household wells to remove remaining traces of oil. • Clean household water with activated charcoal filters.

for recovering light petroleum products off a water table. This device is used successfully in recovering light products like gasoline that have accumulated below leaking tanks. The Scavenger uses a filter system to separate the product from water. Unfortunately the extremely fine sediments that occur on the water tables in Alaska generally quickly clog these filters and as a result, the device has not been totally successful in Alaska. Because of this problem, an alternate method of cleaning the water table was devised.

It has been proposed to dig a trench in a low area of the water table where the spilled product appears to be collecting. The water is generally about 5 to 8 meters deep in this area. The spilled product would collect on the surface of the water filling the trench, and could be recovered with a vacuum truck when the layer of product is relatively thick or with a rope-mop device when the layer of product is relatively thin.

Depending on the conditions at the spill site, additional trenches could be dug to speed the recovery. Round wells could also be dug and the product would be removed using a vacuum truck or some other type of small skimmer such as the Oela weir or the Komara Mini-Skimmer. The type of device that could be used would, however, be limited by the size of the well. The practical problems of performing this operation would be locating the low spot in the water table, and the feasibility of making wells or trenches at the spot where the oil is collecting.

The recovery operation at these wells and trenches would continue until all the available product had been collected. This may take a considerable length of time. Typically when oil is draining into low areas on a water table, the collection effort proceeds rapidly at first, but toward the end of the operation the oil may be leaching into the trench very slowly indeed. For this scenario, the collection effort would have to continue until virtually all of the spilled product had been collected because the taste and odor of the oil would continue to contaminate the water supplies even when only minute amounts remained. This problem is mitigated somewhat by the fact that when the amounts of oil recovered become small, the recovery system can be left unattended and the recovery can continue for a considerable period of time at a relatively low cost. For this scenario it is assumed that nearly all of the spilled product can be collected in about 22 days. This number is somewhat arbitrary, but nevertheless is reasonable because the collection effort for similar spills in Alaska has been completed in about this length of time. The cost of this response effort is based on recovery taking place in 22 days; if the collection effort extends beyond that time it is assumed that the additional expense for the final polishing effort would be relatively low.

Response Level II--

This response level involves recovering product that is leaching into the river. Recall that the amount of oil leaching into the river is relatively small, only about 1.2 Kl per day. It is proposed that several catch basins be dug in the riverbank in the area where the oil is entering the river. This could be a problem because in some areas the river banks are relatively unstable. In any case, it is assumed that these basins could collect about 60% of the oil leaching into the river. Further, it is assumed that about 80% of this oil is recovered using a small rope-mop recovery device. Since the product leaching into the river is highly volatile and has not weathered under ground, about 20% is expected to evaporate during the first day that it is exposed to the air. Since 80% of the leaching oil is recovered and 20% evaporates, it can be assumed that all of the oil leaching into the trench is removed day by day.

The leaching of oil into the trench takes place slowly, therefore a small rope-mop recovery device should be adequate. As the amount of oil entering the trench becomes even less, pad sorbents cleaned in a bucket wringer should be adequate for recovering the oil.

Response Level III--

This response level intensifies the effort of recovering the oil leaching into the river. The collection trenches used in Response Level II were assumed to collect 60% of the oil. This leaves 40% still leaching into the river, which is only 240 liters per day. This oil entering the river will be collected using a containment boom deployed from the shoreline and recovered with a small device located in the apex of the boom. The containment boom will have to be deployed at a very small angle with the river bank, probably about 15°, because the Kuskokwim River can be expected to be running at about 1.4 knots in June. This boom deployment is likely to be fairly successful, and it is assumed that about 75% of the oil still going into the river will be contained by the boom. Of the oil contained by the boom, it is assumed that about 50% can be recovered. Since the product is now spreading more freely on the open water of the river, the evaporation rate goes up to about 50% per day. As a result, about half the oil is recovered and about half evaporates, so that all of the oil behind the boom is gone at the end of each day. The small Morris MI-2 skimmer is intended for use behind the boom since the slick is expected to be quite thin.

In addition to collecting oil behind a boom, Response Level III also provides for a light aircraft to search for product that has accumulated in slack water areas of the river. If such accumulations are found, a crew would be dispatched by boat with a small skimmer to collect the oil. Because the river is broad and swift, and because the spilled product is highly volatile, it is not expected that any appreciable amounts of oil will be collected in this way.

FUEL FARM SCENARIO RESPONSE COSTS

Table 51 shows the cost breakdown for the three spill response levels for the fuel farm spill scenario. The paragraphs that follow comment briefly on the significant response procedures that contribute to these costs.

Cost of Response Level I

The spill response effort begins by using a power auger to drill holes in the spill area to map the extent of the spill. After the general location

TABLE 51. FUEL FARM SPILL COST SUMMARY

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
I.	*Equipment*			
• Recover Oil From Water Table	Cat-350, Backhoe	1	2	234
	Power Auger	3	1	75
• Repair Leak in Fuel Transfer Line	Trash Pumps	3	20	5,310
	CSI Z-14D	1	20	9,200
	Electric Welder	1	2	80
				14,899
	Personnel			
	Spill Control Specialist	1	10	5,400
	Foreman	1	20	8,160
	Equipment Crew	1	2	960
	6-Man Response Crew	9	20	32,640
	Mechanic, Welder	1	2	704
	Logistics	1	20	5,440
				53,304
	Support			
	Consumables	11	20	16,300
	Living Quarters	11	20	6,820
	Transport	-	--	890
				24,010
Site Restoration	Shown with Response Level III			
Total Response Level I				92,213

Continued.

TABLE 51. (continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
II.	*Equipment*			
• Recover Product Leaching into the River	CSI - 14D	1	15	6,900
	Hand Tools	10	15	975
	Sorbents	-	--	267
				8,142
	Personnel			
	3-Man Crew	3	15	12,240
	Support			
	Consumables	3	15	2,925
	Living Quarters	3	15	1,350
				4,275
Total Response Level II				24,657

Continued.

TABLE 51.(continued).

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
III.	*Equipment*			
• Collect Oil Leaching into River	250 Ft Containment Boom	-	15	5,625
	Morris MI-2 Skimmer	2	20	850
• Aircraft Surveillance of Oil in River	Light Aircraft	1	4 hrs	920
	Recovery Boats	2	2	645
				8,040
	Personnel			
	Boat Crews	5	2	2,960
	Shoreline Response Crew	6	5	8,180
				11,140
	Support			
	Consumables	4	5	1,550
	Living Quarters	4	5	600
	Transport	-	--	1,020
				3,170
Site Restoration	• Chlorinate Wells • Filter Water			620
Total Response Level III				22,970

Continued.

TABLE 51.(continued).

COST TO BREAK CAMP

Costs remain the same for all Response Levels.

Transportation

Personnel	$ 910	
Equipment	1,200	
		$ 2,110
Equipment to Cover Trenches	$ 117	
Labor	1,760	
		1,877
Total Cost to Break Camp		$ 3,987

of the spill is known and a low spot in the water table has been identified, a backhoe is used to dig a trench down to the water table. As the trench floods, the oil can be skimmed from the surface. If the accumulation of oil is heavy at first, the oil can be recovered using a vacuum truck. Later, when a thin layer of product accumulates on the water, a skimmer would be used to increase the percent product recovered. In this case the small CSI rope-mop skimmer is suggested. A trash pump is also used to pump water from the trench to accelerate the flow of water from the water table into the trench. It is estimated that this part of the clean-up could be completed in 20 days, although a small amount of product may also be available for recovery for some time after that. The final polishing could take additional time, but this could probably be accomplished with skimmers running unattended.

The leak in the fuel transfer line that contributed to the spill would be identified and repaired concurrently with the spill response effort.

Cost of Response Level II

Response Level II calls for recovering the product that is leaching into the river. This response would be performed in addition to, and concurrent with, the Response Level I effort. This response level therefore requires additional personnel and equipment.

A small trench is dug near the river bank to collect the product that is leaching into the river. It seems likely that this trench could be made with hand tools, but the backhoe could also be used if it were available. The spilled product would be skimmed from the surface of the water in the trench using a second CSI rope-mop skimmer. Since the leaching into the river is proceeding slowly, the skimmer would only be used part time. As the amount of the product present decreases, sorbent pads could be used for recovery. It is estimated that this part of the response effort would take about 15 days.

Cost of Response Level III

Response Level III provides an additional level of effort to recover the product that is leaching into the river, and is performed concurrently with Response Levels I and II. This effort involves deploying a containment boom from the shoreline to collect product that is still leaching into the river. The biggest expense is for the lease of 250 feet of containment boom. Another skimmer, such as the Morris MI-2, would be used to recover the thin slick collecting behind the boom.

A small fixed-wing aircraft would be employed to provide surveillance of the oil leaching into the river. The aircraft would check for visible oil on the water, and if the product was found to be collecting in slack water areas, response crews in power boats would be deployed to recover the oil at those locations. This procedure is the final polishing effort; it is expected to yield only a small amount of recovered oil.

Site restoration would be the same regardless of which response level was employed. Wells would be chlorinated, and activated charcoal filters would be used on all water sources to remove the traces of the spilled product that would likely be present for some time after the response effort was completed.

ENVIRONMENTAL IMPACT FOR THE FUEL FARM SPILL

The environmental impact for the fuel farm spill is computed in the same manner as was used for the other scenarios; however, the fuel farm spill situation is somewhat different from the other spill scenarios.

The fuel farm spill, like the oil well blowout, occurs in a way that the area covered by the spill does not change much as the recovery effort progresses. Since most of the spill is on the water table, the exact area covered by the spill can only be estimated. In addition, as the response effort continues, the volume of the spill decreases but the area is likely to remain about the same until the response effort is nearly complete. In this case, the change in spill impact is still represented by the change in the volume of the product remaining. The change in spill area is assessed for that part of the spill that leaches into the river.

In the fuel farm spill the recovery effort for the three response levels occurs concurrently, therefore the spill impact is computed at the beginning of the response effort and at the end.

Table 52 shows the fuel farm spill sensitivity. This table is the same as the corresponding tables for the other scenarios except that several categories of spill sensitivity do not occur in this scenario and are therefore eliminated to shorten the table. The categories that are eliminated are:

- Permafrost - The permafrost at McGrath is below the water table and would not be affected.

- Wetland Habitats - These areas would only be affected at the flood stage of the river.

- Upland Habitats (Vegetated) - Oil would not reach upland habitats other than beaches which might be lightly coated with oil as water levels receded.

- Birds (Non-Water Related) - None would be affected. As river levels receded, the oil coating the shorelines would be so diffused as to cause no measurable effect on the birds that might use the habitat.

- Mammals (Water Related) - Few, if any, would use habitats affected by oil in the early stages of the spill. As river levels receded, oil would be so diffused that it would have no measurable effect on mammals using the shoreline.

TABLE 52.

FUEL FARM SPILL SENSITIVITY

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Soil Stability	
(1) Riverbank soil at the point where the oil emerges would be rendered slightly unstable by the oil.	(1) Effects of cleanup would be adverse, but slight.
Aquatic Habitats (fresh)	
(1) During the period that the river is at high spring runoff stages it would be turbid and turbulent and dissolved fractions of the oil would be dispersed. The oil and water mixture, some adsorbed to silt particles, would not be measurable more than 20-30 km downstream. The mainstem Kuskokwim River is migration habitat for fish, but supports little else at this season. Water quality would be slightly reduced.	(1) Small amount of product would continue to leach into aquatic habitat.
Upland Habitats (unvegetated)	
(1) Oil would not reach upland habitats other than beaches. These might be lightly coated with oil as water levels receded.	(1) Light coating of beaches unaffected by recovery effort.

(Continued)

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TABLE 52.(Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Soil Stability	
(1) Adverse effects still slight.	(1) No further effects on soil stability.
Aquatic Habitats (fresh)	
(1) Same as I at left.	(0) Most leaching of product into the river has stopped as a result of the boom and collection pool and collection in downstream slack waters.
Upland Habitats (unvegetated)	
(1) Same as I at left.	(1) Same as I at left.

(Continued)

TABLE 52. (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Finfish	
(1) Outmigrant salmon would no longer be in the river at this season and would not be affected. A few early upstream migrant salmon, as well as other species such as whitefish holding in eddies, could be slightly affected by toxic elements dissolved in the water column. Oil would be too diluted at the river mouth to affect homing into the Kuskokwim system and ability of fish to home into uncontaminated tributaries would not be affected.	(1) Little effect from recovery effort.
Birds (water-related)	
(1) Few birds would be in the river. The few that were would be lightly coated by dispersed oil with only slight effects. Only a light skim of oil would remain on shorelines as river levels receded.	(1) Light coating of oil would remain on beaches.
Mammals (non-water-related)	
(0) Few, if any, would use habitats affected by oil in the early stages of the spill. As river levels receded, oil would be so diffused that it would have no measurable effect on mammals using the shoreline.	(0) NA
Wilderness	
(1) Areas downstream from McGrath have characteristics of wilderness. A noticeable sheen of oil on the water surface would have slight temporary adverse effects.	(1) Leaching of oil into river would continue for a period.

(Continued)

TABLE 52.(Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Finfish	
(1) Same as I at left.	(0) Booming and collection at spill site and downstream slack water reduce effects to insignificant.
Birds (water-related)	
(1) Same as I at left.	(1) Same as I at left. (If product trapped in backwaters was significant in quantity, cleanup would benefit these birds, but only small amounts of oil are expected in these areas.)
Mammals (non-water-related)	
(0) NA	(0) NA
Wilderness	
(1) Same as I at left.	(0) Collection of oil leaching into river at spill site would shorten time to recovery and would reduce effects of spill to insignificant.

(Continued)

TABLE 52. (Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Human Domestic Use of Water	
(3) Although some wells would be closed, other water supplies are nearby. The situation is likely to become more widespread, however. A complicating factor is the dangerous condition of most wells before the spill, which suggests that the community would soon be forced to seek other water sources in any event.	(2) Spread of contaminant halted. (Bacteriological problems remain.)
Human Use of Fish	
(1) Whitefish and salmon taken downstream from the spill site would be tainted but most not so severely as to be totally unusable. Fishing gear used downstream from the spill would be lightly coated by oil.	(1) Little immediate effect from response.
Other Community Activities and/or Facilities	
(1) The primary contaminated zone is heavily used for everyday vehicle and foot traffic, which would be forced to detour or contact oil, thereby spreading the effects. Boats downstream from the spill would be lightly coated by oil.	(1) Most problems at the spill site would be alleviated rapidly by shutting off the leak. Boats in the river would still be oiled.
Aesthetic Quality	
(3) Proximity to dwellings and other community activities would intensify the effect. Tracking of oil into homes, oil on boats, and in vehicles and aircraft would have long-term severe adverse aesthetic effects.	(1) Effect of repairing leak would be immediate, as would surface cleanup. Oil on boats would remain.

(Continued)

TABLE 52.(Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Human Domestic Use of Water	
(2) Further containment of spread of contaminants (no effect on bacteriological problems).	(2) We do not believe chlorination would affect distribution of petroleum products. It would alleviate bacteriological problems temporarily. Charcoal filters would improve taste. Its effect on dissolved toxic elements uncertain.
Human Use of Fish	
(1) Same as I at left.	(0) Catching the product as it leaches into the river would reduce problem to insignificant.
Other Community Activities and/or Facilities	
(1) Same as I at left.	(0) Catching the oil as it leached into the river would remove the problem of oiled boats.
Aesthetic Quality	
(1) Little further effect over I.	(0) Remaining problems would be insignificant as further flow of product into the river has stopped.

- Human Use of Birds - Few birds would be contaminated, and those only slightly. The probability of humans making use of such tainted birds would be very low.
- Human Use of Mammals - Few mammals would be contaminated, and those only slightly. The probability of humans making use of such tainted mammals would be very low.

FUEL FARM SPILL RESPONSE EFFECTIVENESS

As before, the spill response effectiveness following the fuel farm spill is a function of the area covered by the spill, the volume of the spill remaining on the water table and in the river, and the sensitivity of the various environmental factors to the spilled oil. This section reviews the results of these computations.

Volume of Oil Recovered During Each Response Level

The volume of oil spilled is the controlling variable in determining spill impact and response effectiveness for this scenario. Table 53 shows that most of the product is recovered in Response Level I. This is a result of the circumstances of the scenario. The spilled oil on the water table is in place and will remain to contaminate water supplies until it is recovered. Recovering an arbitrary amount, such as 50% of the spill, is not acceptable in this situation as it might be for an open water spill. In this case, virtually all of the spill must be recovered to clean the water supply. This, of course, influences the results of the effectiveness analysis, which shows a high level of effectiveness for Response Level I. This could not be helped since it is a function of the problem constraints. As is the case for many spills on land, the minimum acceptable level of response calls for a very high percentage of the total spill to be recovered.

TABLE 53 VOLUME OF SPILL RECOVERED FOR FUEL FARM SPILL SCENARIO

Response Level	Volume Recovered	
	m^3	BBL
I	94.6	595
II	6.7	42
III	2.1	13
TOTAL	103.4	650

Fuel Farm Spill Response Effectiveness Computation

The spill response effectiveness is determined by computing the spill impact, which is the product of the volume, area, and sensitivity, and comparing the impact for each response level with the impact with no spill response. Table 47 shows the details of the method used in making these calculations. Spill sensitivities are taken from Table 52.

Table 54 below summarizes the results of these calculations for the fuel farm spill.

TABLE 54 FUEL FARM SPILL IMPACT AND RESPONSE EFFECTIVENESS

Response Level	0	I	II	III
Impact (m^5)	$1.81 \cdot 10^7$	$1.73 \cdot 10^5$	$8.81 \cdot 10^4$	$2.41 \cdot 10^4$
Response Effectiveness	--	0.990	0.995	0.999

Table 54 shows that the spill response effectiveness is very high for Response Level I and increases only slightly for Response Levels II and III. This result could be predicted by noting the volume of oil recovered in Response Level I. This result is likely for any spill on land in a sensitive area where the minimum acceptable level of response requires that nearly all of the spill be recovered. Further, because of the way in which the spill response effectiveness is defined, this result can be expected any time there is more than an order of magnitude difference between the impact with no response and the impact with the minimum level of response. This could occur in nearly any large spill since the difference over time in the volume of oil spilled and the area covered by the spill is likely to be large.

COST EFFECTIVENESS OF FUEL FARM SPILL RESPONSE

Cost effectiveness is defined as the quotient of normalized cost and response effectiveness. Figure 59 shows a plot of the cost effectiveness for the three fuel farm spill response levels. The curve does not have a minimum, therefore Response Level I, which gives the lowest numerical value for cost effectiveness, is the cost effective solution. Since the response effectiveness is nearly the same for each response level, this simply shows that the additional cost of the higher levels of response appears to be reasonable in terms of the level of effectiveness achieved.

This evaluation is only partly true, however, because spill response effectiveness is a cumulative value. That is, the effectiveness of Response Level II includes the results of Response Level I. When Response Level I is very high, the cumulative value is also going to be high. Because of this, it is also instructive to look at the differences between the response levels.

Figure 60 shows the incremental cost per barrel of oil recovered for each response level. This is not the accumulated cost, but rather the cost of recovering the additional barrels of oil. As always, cleaning up a thin slick is expensive in terms of the amount of oil that is recovered. The cost per barrel of oil recovered in Response Level II is quite high, and the cost per barrel recovered for Response Level III is so high that this recovery effort is probably not worth the price. If the Kuskokwim River were

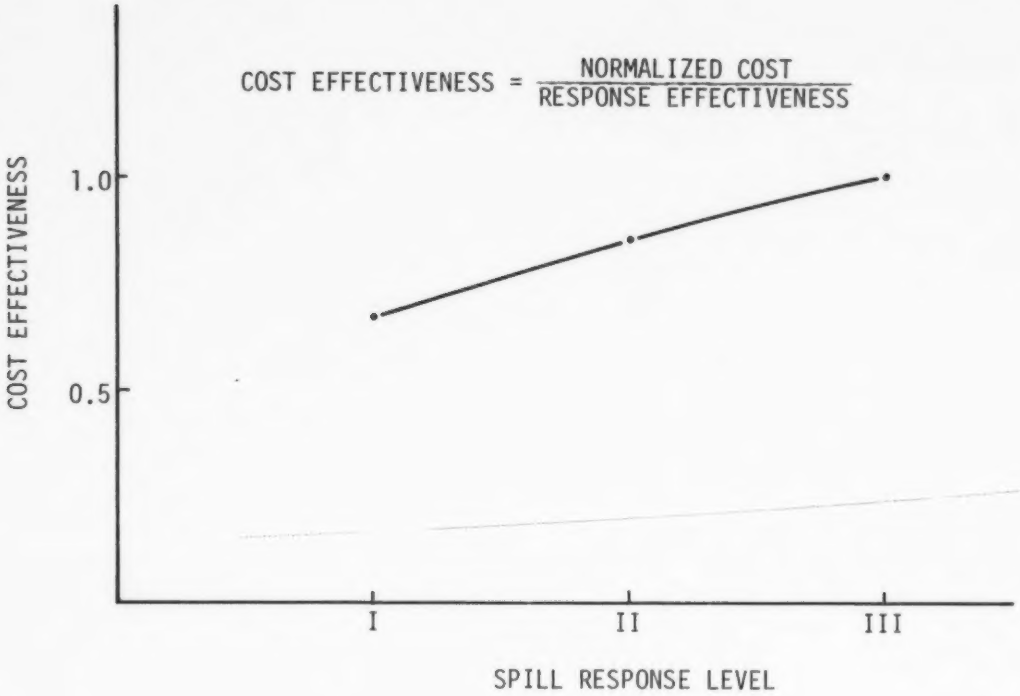

Figure 59. Fuel farm spill cost effectiveness vs spill response levels.

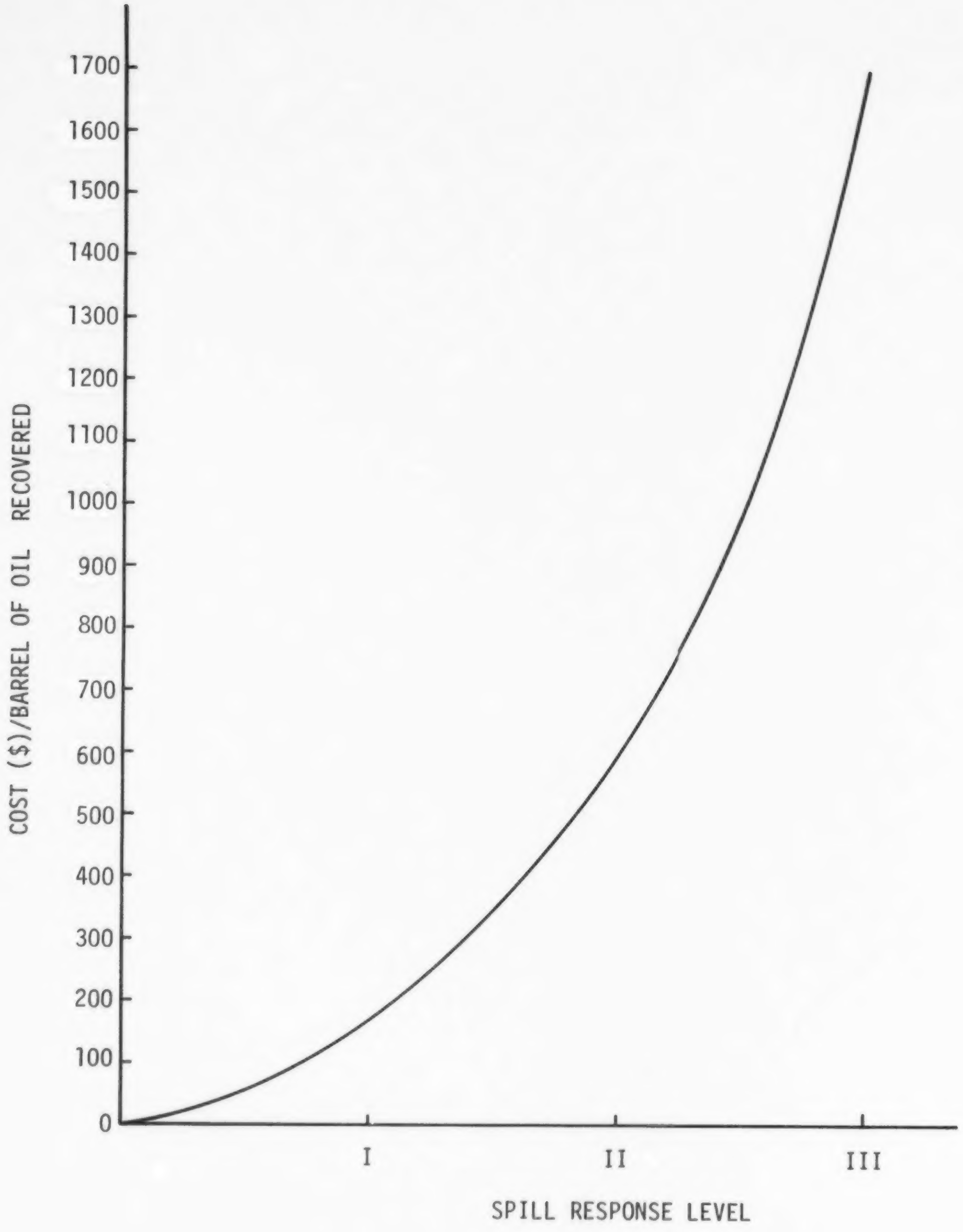

Figure 60. Fuel farm spill cost/barrel of oil recovered vs spill response level. (This graph shows the cost of recovering the additional oil picked up at each response level.)

highly sensitive to the spill, then Response Level III may be worth the cost. Table 52 shows that the sensitivity of the river to the spill tends to be low, and the spill is likely to be lost to evaporation in a short time even if no response effort occurs. This leads one to make the observation that the expenditure of a large effort on a small but visible slick should be avoided unless there is an appreciable threat of environmental damage.

Figure 61 shows the percent oil recovered for each spill response level. This is the percent recovered in each response level, not the cumulative percent recovered to that point. The figure shows that most of the spill is recovered in Response Level I. The dollar cost for each percentage point removed is also shown. It is apparent that the cost for removing the smaller amounts of product increases sharply in the higher response levels.

Summary of the Fuel Farm Spill Effectiveness Analysis

The analysis of the fuel farm spill scenario shows that the lowest acceptable level of response is also the most cost effective. This result occurs because the minimum acceptable level of response is quite high, and also because the higher levels of response collect only a small amount of oil and are not significant in preventing environmental damage. Response teams may be compelled to clean the product from the river because it is visible, even though this may be only a small fraction of the oil that is being recovered from the water table, where it is not visible. Although the response effort planned for Response Level III does reduce spill impact, it may not be economically justified.

R&D INITIATIVES SUGGESTED BY THE FUEL FARM SPILL SCENARIO

Response Level I

In the fuel farm scenario, the area of the spill on the water table cannot be determined from the surface. The only way to map the area of the spill is to drill holes in the ground until spill locations are discovered. This method is slow, expensive, and destructive to the terrain. It would therefore be useful to have a device that could sense the presence of underground oil from the surface.

Response Level I involves digging a trench to collect oil from the water table. This procedure is suggested because the device normally used for recovering product from a water table becomes clogged with the fine Alaskan sediments. It would be useful, therefore, to develop or identify a skimmer that would not become clogged with these sediments and which could be used in a small well. Having such a device would reduce the spill response impact to the topography, such as the impact of digging large trenches, and would also reduce the labor cost of recovery because the device could probably be allowed to run unattended.

Response Levels II and III

No additional R&D initiatives are suggested by Response Levels II and III.

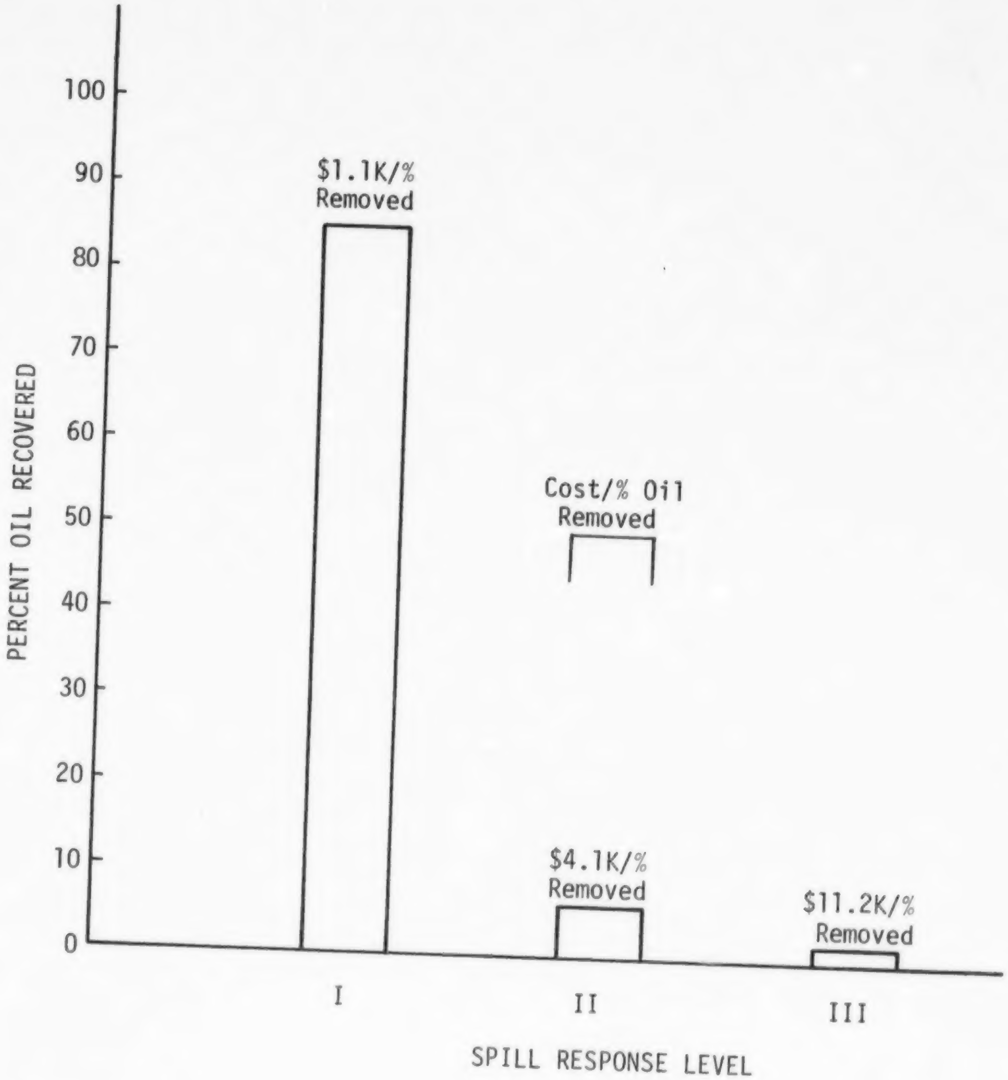

Figure 61. Fuel farm spill percent oil recovered vs spill response level.

TANK TRUCK SCENARIO RESPONSE METHODS

The Tank Truck Spill Response Problem

The tank truck overturns and the spilled product quickly moves down the slope over the wet terrain into Hess Creek. Since the slope is steep, the spill is expected to begin leaching into the creek in a little more than four hours after the spill occurs. The diesel fuel is likely to be highly toxic to the fresh water fish in the creek; therefore, the environmental impact of the spill will occur quickly and for the population of fish that are affected, the damage will be permanent. The basic problem is to begin the spill response effort early enough to minimize the impact of the diesel oil on the stream. Since the spill occurs in a remote area, at least four to six hours are likely to elapse before help arrives.

There would also be a problem in applying effective spill response measures once help did arrive. The thin slick of diesel fuel leaching into Hess Creek would be difficult to contain and recover. Likewise it would be difficult to clean the soiled vegetation and ground. In fact, intensive cleaning measures could be more damaging to the ground and the vegetation than leaving the spill in place. Leaving the spill in place, however, could result in the destruction of the ground cover, damage to the permafrost layer if one exists, and heavy erosion of ground in the area where the spill occurred.

Tank Truck Spill Response Methods

Table 55 summarizes the spill response methods proposed for the tank truck spill. The paragraphs that follow provide additional details concerning the methods proposed.

Response Level I--

The first measure suggested for spill response is to burn the spill on the ground as soon as this procedure can be safely attempted. This measure has a number of important advantages and disadvantages, and because the concept of burning is highly controversial, alternate methods of spill response are also proposed for Response Level I.

First consider the advantages of burning. The spill may ignite as the accident occurs, in which case no other alternatives for response are available. If the spill does not ignite accidentally, consider the possibility of intentionally igniting the spill. Burning will have to occur while the volatile components of the product are still present. At the same time, burning is not likely to be safe until the ruptured tank has emptied because this could cause an explosion or fire at the truck. Since it is estimated that the damaged truck would be emptied in about 20 minutes, burning could begin soon after the spill occurred.

Perhaps one of the chief advantages of burning is that most of the spill could be eliminated before it begins to contaminate the creek, which is the area of highest environmental sensitivity. In addition, the burn

TABLE 55. TANK TRUCK SPILL RESPONSE METHODS

	RESPONSE ACTION
RESPONSE LEVEL I	
• Clean Area Where Product Has Spilled	• Send a recovery tank truck to empty product remaining in overturned truck. • Burn spilled product. If Fire is Not Permitted: • Dig a small trench adjacent to Hess Creek and collect product leaching down from spill. Flush with low pressure water; recover oil with sorbents. • Clean visible product contained by vegetation using sorbents.
RESPONSE LEVEL II	
Level I Plus - • Recover Product That Is Leaching Into Creek	• Deploy a diversionary boom a short distance downstream to divert product into an abandon meander; close outlet end of meander and recover product in calm waters. • Recover product that collects naturally in pools and slack water areas.
RESPONSE LEVEL III	
Levels I and II Plus - • Recover Product Observed Further Downstream	• Dig scallops in riverbank downstream to collect product in backwater areas; collect product with sorbents or a skimmer. • Use helo for surveillance downstream; land crew if recoverable amount of oil is sighted.
RESPONSE LEVEL III	SITE RESTORATION
	• Light fertilization to speed revegetation. • Sow arctic grass where bare ground may be affected by erosion.

would remove most of the spilled product from the ground, a task that may be difficult to complete by other means. The decision to burn depends on the condition of the ground. Burning is not recommended if the ground is dry because there could be deep and more permanent damage to the vegetation. However, if the ground is quite wet, advocates of burning believe that there would be only minimum damage to the vegetation. In fact, some hold that the burning would prepare the ground for new vegetation and that new growth would become established more quickly than if the oil were left in place or cleaned by some other means. The argument is that fire is a natural disturbance in this area and that plants are adaptable to surviving fires.

Other highly qualified scientists in Alaska hold the opposite view concerning the use of fire. These individuals believe that fire would destroy the vegetative mat and intensify the damage regardless of the condition of the ground. They believe that burning would prolong the damage in every case. It must be noted that burning as a spill response measure would require permission from the responsible State authorities. In many cases State officials have been opposed to burning.

Burning is mentioned as a spill response measure because this technique does have many advocates among spill response specialists in Alaska, both in and out of government. The fact that opinion is divided among advocates and opponents has led us to only mention this method as an alternative. Spill response effectiveness and response costs are actually computed using a different response method not involving burning.

Response Level I for this scenario consists of digging a small trench adjacent to Hess Creek and lining it with plastic to collect the oil that is leaching down the slope into the river. In addition, a pump is used in the river to bring water up for low pressure flushing to remove spilled oil from the vegetation and porous earth and collect it in the trench. The low pressure flushing must be done carefully or it could be more damaging to the terrain than leaving the spill in place. Since the amount of oil being collected is small, the oil could be recovered from the trench using sorbents. In addition, visible oil that is pooled or contained by the vegetation or earth would also be recovered with sorbents. It is expected that this effort would be completed in about two days.

Response Level II--

Response Level II involves recovering spilled product from the creek near the spill site. This would be done by deploying a containment boom a short distance downstream to divert oil into an abandon meander. The outlet of the meander would be closed and the oil would be recovered in calm water. There could be some problems in deploying the containment boom because the creek is likely to be shallow in July, and it is expected to have a current of about 1 knot. The return from this response effort is likely to be low. In addition to diverting the spill into slack water areas, an attempt would be made to recover the product that has collected naturally in pools and slack water areas.

Response Level III--

This response level would be a final effort to collect additional oil from the river. In this case, scallops would be dug in the river bank downstream of where the oil has been observed on the water. A log would be used just upstream of the collection pools to create a backwater area to collect the oil for recovery. The oil collecting in these pools would be recovered using a small skimmer or sorbents. Digging scallops in the river bank is, in the opinion of some observers, more damaging to the environment than leaving the oil to evaporate or degrade naturally. This alternative is proposed because it is one of the few methods remaining to recover additional oil from the river, and it was suggested by several spill response specialists in Alaska.

As a final effort to recover oil from the river, a helicopter would be used for surveillance downstream for the purpose of landing a small response crew to collect any oil that can be identified.

TANK TRUCK SCENARIO RESPONSE COSTS

Table 56 shows the cost breakdown for the three spill response levels for the tank truck spill scenario. The paragraphs that follow comment on the response procedures that contribute significantly to these costs.

Cost of Response Level I

Response Level I begins by sending a wrecker and a fuel transfer truck to the spill site to assist the overturned truck. Pumping the remaining fuel from the truck is not counted as spill recovery, but it is a function that must be performed.

Cleaning up the spill site is a simple operation from the point of view of response equipment. The proposed response methods just require hand tools, a pump for low pressure flushing, and sorbents, mops, and a wringer for recovering the oil in a collection trench.

Cost of Response Level II

Response Level II requires containment boom, two small skimmers, and sorbents. The costs of labor are the largest expense.

Cost of Response Level III

Response Level III calls for an attempt to recover product that is observed farther downstream. The big expense for this effort is the cost of the helicopter. This effort is not likely to be considered cost effective in terms of the amount of product that is collected.

ENVIRONMENTAL IMPACT FOR THE TANK TRUCK SPILL

The environmental impact for this scenario is computed in the way described on Table 47 except that the impact at the time the spill occurs,

TABLE 56. TANK TRUCK SPILL COST SUMMARY

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
I.	*Equipment*			
• Clean Ground at Spill Site	Wrecker and Transfer Tank Truck	2	1	1,400
	Hand Tools	-	2	84
	Pump	1	2	177
	Sorbents, Mops, Wringer	-	2	842
				2,503
	Personnel			
	Spill Control Specialist	1	2	1,080
	Foreman	1	2	816
	6 Man Crew	6	2	3,264
				5,160
	Support			
	Consumables	8	2	1,140
	Living Quarters	1	2	220
	Transport*	-	-	426
				1,785
Total Response Level I				9,449

---

* Because this is a small response effort, separate break-camp costs do not apply. Transport for Response Level I includes round-trip transport for equipment and vehicles.

(Continued)

TABLE 56.(Continued)

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
II.	*Equipment*			
• Recover Product Leaching Into Creek	Containment Boom	1	1	150
	Morris MI-2	2	1	100
	Sorbents	-	-	267
				517
	Personnel			
	Spill Control Specialist	1	1	540
	Foreman	1	1	408
	6 Man Crew	6	1	1,632
				2,580
	Support			
	Consumables	8	1	570
	Living Quarters	1	1	110
	Transport	-	-	50
				730
Total Response Level II				3,827

(Continued)

TABLE 56. (Continued)

RESPONSE LEVEL/ACTION	RESPONSE REQUIREMENTS	UNITS REQUIRED	DAYS REQUIRED	RESPONSE COST
III.	*Equipment*			
• Recover Product Observed Downstream	Hand Tools	-	1	72
	Sorbents	-	1	266
	Helicopter	1	8 hrs	3,200
				3,538
	Personnel			
	Spill Control Specialist	1	1	540
	Foreman	1	1	408
	6 Man Crew	6	1	1,632
				2,580
	Support			
	Consumables	8	1	570
	Living Quarters	1	1	110
	Transport	-	-	50
				730
Site Restoration				
Light Fertilization of Area				
Sow Arctic Grass in Bare Areas				100
Total Response Level III				6,948

shown in column one, is not used. This is done because of the tremendous area that the spill covers on the river soon after the spill begins to leach into the water. This thin slick is quickly carried downstream and evaporates in less than a day. While the spill is on the water, however, it covers a very large area. Since the impact includes the product of the area times the volume, the impact at time zero, or the first day, is also very large. The product of area, volume, and sensitivity in this case is of the order of 10^8, yet after the spill on the water evaporates, the impact is of the order of 10^3. If the impact at time zero is added to the impact after other response levels have been completed, the change in impact due to the spill response effort will be completely lost in the larger number. Starting the impact computation after time zero is a sound practice and, in fact, this is the method that was employed in the Coast Guard study previously cited; however, it does not adequately represent the level of impact that occurs on the first day of the spill. On the first day of the spill a heavy toxic load flows into the creek; fish are tainted and biological life is destroyed. The fact that the product has evaporated from the river by the second day does not change the damage that has already been done. This damage will therefore be noted, but it cannot be represented in the impact computations.

Table 57 shows the environmental sensitivity for the tank truck spill. The numbers are used to compute the spill impact and the response effectiveness.

TANK TRUCK SPILL RESPONSE EFFECTIVENESS

Volume of Oil Recovered During Each Response Level

In this scenario the area covered by the spill is the controlling variable rather than the volume spilled; however, it is still instructive to consider the volumes of product recovered since this is the most obvious on-site measure of effectiveness. Table 58 shows the volume of spill recovered for each response level.

TABLE 58 VOLUME OF OIL RECOVERED FOR THE TANK TRUCK SPILL SCENARIO

Total Volume Spilled = 30.3 m^3 (8,000 gallons)

Response Level	Recovered (m^3) at Each Level	Amount Recovered (m^3) (Cumulative)	% Recovered (Cumulative)	% of Amount Available for Recovery
I	2.0	2.0	6.6	59
II	0.24	2.24	7.4	66
III	0.04	2.28	7.5	67

The volume of spilled oil recovered in this scenario is not impressive, but most of the spill is not available for recovery. A large part of the spill goes into Hess Creek before any response action can be taken and

TABLE 57.

TANK TRUCK SPILL SENSITIVITY

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Soil Stability	
(4) Oil spilled on the slope during the accident would penetrate through the vegetation mat, killing vegetation, and would cause severe erosion problems in the loamy soils of the spill site. If permafrost or ice lenses were involved, there would be persistent slumping for an extended period.	(4) A burn, if successful, would destroy remaining vegetation mat and itensify damage. Vegetation would be killed, regardless, and recovery would be slow.
Permafrost	
(4) Any permafrost or ice lenses beneath the surface on which oil was spilled during the accident would suffer loss of thermal insulation through destruction of protective vegetation cover and alteration of albedo. There would be persistent permafrost or ice lens degradation.	(4) Same as above.
Acquatic Habitats (fresh)	
(3) Highly toxic diesel fuel leaching into Hess Creek would have short-term localized adverse effects on biota of the creek. Persistent long-term soil erosion from the slope would have long-term effects on the entire stream down to the Yukon River. Silt would smother the streambed, reducing productivity and degrading spawning habitats.	(3) Most toxic effects on stream and slack waters occurred before response began. Effects would be severe, even with reduction of flow into creek.

(Continued)

TABLE 57. (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Soil Stability	
(4) Same as I at left.	(4) Same as I and II at left, except that use of fertilizer might accelerate recovery. This would be offset by scallops in riverbank downstream which would erode.
Permafrost	
(4) Same as above.	(4) Same as I and II at left. Recovery of vegetation would not result in immediate halt of permafrost degradation.
Acquatic Habitats (fresh)	
(3) Little effect beyond Level I on either toxicity or eventual bank erosion.	(4) Little ameliorating effect beyond Level I. Scallops in riverbank would create long-term siltation problems. Excessive fertilizer might be detrimental.

(Continued)

TABLE 57.(Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Upland Habitats (vegetated)	
(4) Spilled oil would kill vegetation and destroy soil organisms on the bank down which the spill occurred. Productivity of this habitat would be destroyed.	(4) Attempts to burn, whether or not they were successful, would only prolong the damage.
Wetlands	
(3) There would be immediate short-term local degradation from the toxic oil as it spread across the bog through water-filled interstices. Long-term effects would result from silt washed down from the eroding slope. Effects on habitat productivity would be localized but severe.	(4) Trenching of wetlands near Hess Creek would contribute further long-term damage to a small amount of wetlands.
Finfish	
(3) There would be a short-lived, highly toxic plume for a short distance downstream from the spill that would kill or disable fish. Effects downstream would diminish as oil became mixed with creek water and diluted. Siltation from the eroding bank would reduce spawning success of salmon, whitefish, and other species of fish. These species would also be affected by reduced productivity of feeding and rearing habitat.	(3) Response effort would be too late to reduce toxic effects significantly.

(Continued)

TABLE 57. (Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Upland Habitats (vegetated)	
(4) Same as I at left.	(3) Application of fertilizer, after toxicity of soil had been leached and weathered away, might expedite recovery.
Wetlands	
(3) Recovery of product from water-filled interstices of wetlands would have a minor effect on recovery of flora and fauna.	(4) Scallops on riverbank would cause long-term damage to wetlands.
Finfish	
(3) Diversionary boom would collect a small amount of product, but its toxic portions would already have entered the water column.	(4) Use of fertilizer to stabilize soil would be more than offset by the siltation of spawning and rearing habitat by scallops cut in riverbank downstream. Excessive fertilizer might be toxic.

(Continued)

TABLE 57.(Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Birds (water-related)	
(2) A few ducks and other water birds would be contaminated by spilled fuel and would be immobilized. Juveniles would be killed by the oil. Long-term reduction of habitat productivity would stress those birds otherwise unaffected, which would be forced to move elsewhere or to survive under adverse conditions.	(2) The damage to birds would already have occurred before response. Ameliorating effects of response would be slight.
Birds (non-water-related)	
(2) Ground-nesting birds and some other birds present on the slope at the time of the accident would be killed by the oil or by the truck itself. Other birds would escape and be little affected. They would also suffer from long-term loss of habitat along the bank.	(2) Response effort would have no significant effects.
Mammals (water-related)	
(2) Mink, beaver, and otter in the creek and in wetlands downstream from the spill would be contaminated and might also eat contaminated food. Moose at this season also feed in water areas and would probably be denied the use of oil-covered areas. Reduction of habitat productivity would have long-term adverse effects on beaver, mink, and otter.	(2) Response effort would have no significant effects.

(Continued)

TABLE 57.(Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Birds (water-related)	
(2) Some benefits from collecting remaining product from slack water, but they would be small.	(2) No further benefits beyond Level II.
Birds (non-water-related)	
(2) Same as I at left.	(1) Immediate effects would not be reduced, but application of fertilizer might expedite recovery of bird habitats on the slope.
Mammals (water-related)	
(3) Same as I at left.	(2) Same as I at left.

(Continued)

TABLE 57.(Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Mammals (non-water-related)	
(3) Small mammals (shrews and voles) in the spill area would be severely affected and most would be killed. Large mammals would be affected only by reduction in habitat productivity and contact with contaminated prey or carrion.	(2) Response effort would have no significant effects.
Human Use of Vegetation	
(1) Berries on the bank where the spill occurred would be unavailable for use for an extended period.	(1) Response effort would have no short-term effects.
Human Use of Fish	
(2) Fish that survived the oil spill would be tainted for a short period. There would be a slight long-term reduction in numbers of fish available.	(2) Response would have no measurable effect.
Human Use of Birds	
(2) The wetlands and stream reaches affected by the spill are at a road crossing and are accessible for human use. Availability of birds for human use would be diminished by the effects of the spill. Some birds taken for food might also be tainted by oil.	(2) No measurable effect from response efforts.

(Continued)

TABLE 57.(Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Mammals (non-water-related)	
(3) Response effort would have no significant effects.	(2) Only effect of response effort would be from application of fertilizer, which might expedite recovery of habitat on slope.
Human Use of Vegetation	
(1) Same as I at left.	(0) A successful burn coupled with application of fertilizer might result in growth of berry producing plants.
Human Use of Fish	
(2) Same as I at left.	(2) Same as I at left.
Human Use of Birds	
(2) Same as I at left.	(2) Same as I at left.

(Continued)

TABLE 57.(Continued)

NO RESPONSE IMPACT/RATIONALE	RESPONSE LEVEL I IMPACT/RATIONALE
Human Use of Mammals	
(2) The small amount of habitat that would be affected is accessible to human use. Reduction in numbers of mammals and their use of the area would reduce opportunity for human use.	(2) No measurable effect from response efforts.
Other Community Activities and/or Facilities	
(2) Enjoyment of picnicking, photography, and other outdoor recreation typical of road crossings of clear streams in Alaska would be impaired.	(2) No measurable effect. Slight effect from oil removal would be offset by burning and trenching.
Endangered Species	
(1) There is a very slight possibility that a peregrine falcon might become contaminated slightly by contact with oiled prey from the spill area. Trumpeter swans, formerly endangered, have been reported in the region, but Hess Creek is not attractive trumpeter swan habitat.	(0) Removal of visible product would reduce possibility of a peregrine falcon being affected by contaminated prey.
Aesthetic Quality	
(3) Scenic values of a highway crossing of a clear stream would be severely impaired by presence of oil in the water and marsh and the erosion of the bank at the spill site.	(3) Response effort would have no measurable effect.
Air Quality	
(1) Air quality would be adversely affected by the odor of spilled oil in the area.	(1) Although effects on air quality from the spill are insignificant, attempts to burn the spilled fuel would cause considerable smoke.

(Continued)

TABLE 57.(Continued)

RESPONSE LEVEL II IMPACT/RATIONALE	RESPONSE LEVEL III IMPACT/RATIONALE
Human Use of Mammals	
(2) No measurable effect from response efforts.	(2) No measurable effect from response efforts.
Other Community Activities and/or Facilities	
(2) Same as I at left.	(1) Little additional effect beyond Level II except that application of fertilizer might expedite recovery of slope.
Endangered Species	
(0) Same as I at left.	(0) Same as I at left.
Aesthetic Quality	
(3) Same as I at left.	(3) Application of fertilizer might expedite recovery of bank, but this would be offset by the scallops in the stream banks downstream from the spill.
Air Quality	
(0) Burning the fuel gathered in Level II response would create perceptible smoke.	(0) No effect on air quality from Level III.

evaporates so quickly that it is not available for recovery. Because of this, Table 58 also shows an estimate of percent recovery based on the amount of oil that is reasonably available for recovery. These numbers make the response effort look more successful. These figures show that a fair amount of the spill on the ground is actually recovered.

Tank Truck Spill Response Effectiveness Computation

Table 59 shows the results of the calculations of spill impact and response effectiveness for the tank truck spill scenario.

TABLE 59 TANK TRUCK SPILL IMPACT AND RESPONSE EFFECTIVENESS

Response Level	0	I	II	III
Impact (m^5)	$6.03 \cdot 10^4$	$7.08 \cdot 10^3$	$6.43 \cdot 10^3$	$5.63 \cdot 10^3$
Response Effectiveness	--	0.88	0.89	0.91

Spill response effectiveness is quite high for Response Level I, and since only small volumes of the spill are recovered on the river, response effectiveness increases only slightly for Response Levels II and III. These calculations do not include the amount of the product that has evaporated as "recovered" because this would make the response effectiveness for all response levels unrealistically high, and would not show the relative effectiveness of each response level.

COST EFFECTIVENESS OF TANK TRUCK SPILL RESPONSE

Figure 62 shows a plot of cost effectiveness for the tank truck spill. Since this curve does not have a minimum, the lowest value represented by Response Level I is the cost effective solution. Further, the slope of the curve is steep showing that the increase in cost per unit of effectiveness is then high for Response Levels II and III. Response Levels II and III spend a relatively large amount of money in pursuit of a very small amount of oil that remains in Hess Creek. As a practical matter, the greatest damage done to the stream is a result of the load of product that enters the stream soon after the spill occurs. Even though most of this part of the spill evaporates quickly, this damage cannot be undone, and the oil that is collected off the water does little to reduce the impact. The key here is to keep the spill out of the stream. This could possibly be accomplished by using burning as a spill response measure, or by deploying a response crew very quickly to keep the spill out of the stream entirely.

Figure 63 shows the incremental cost of recovering additional barrels of oil for each response level. Since only a small amount of product is recovered for Response Level III, the cost per barrel of recovering this part of the spill is high.

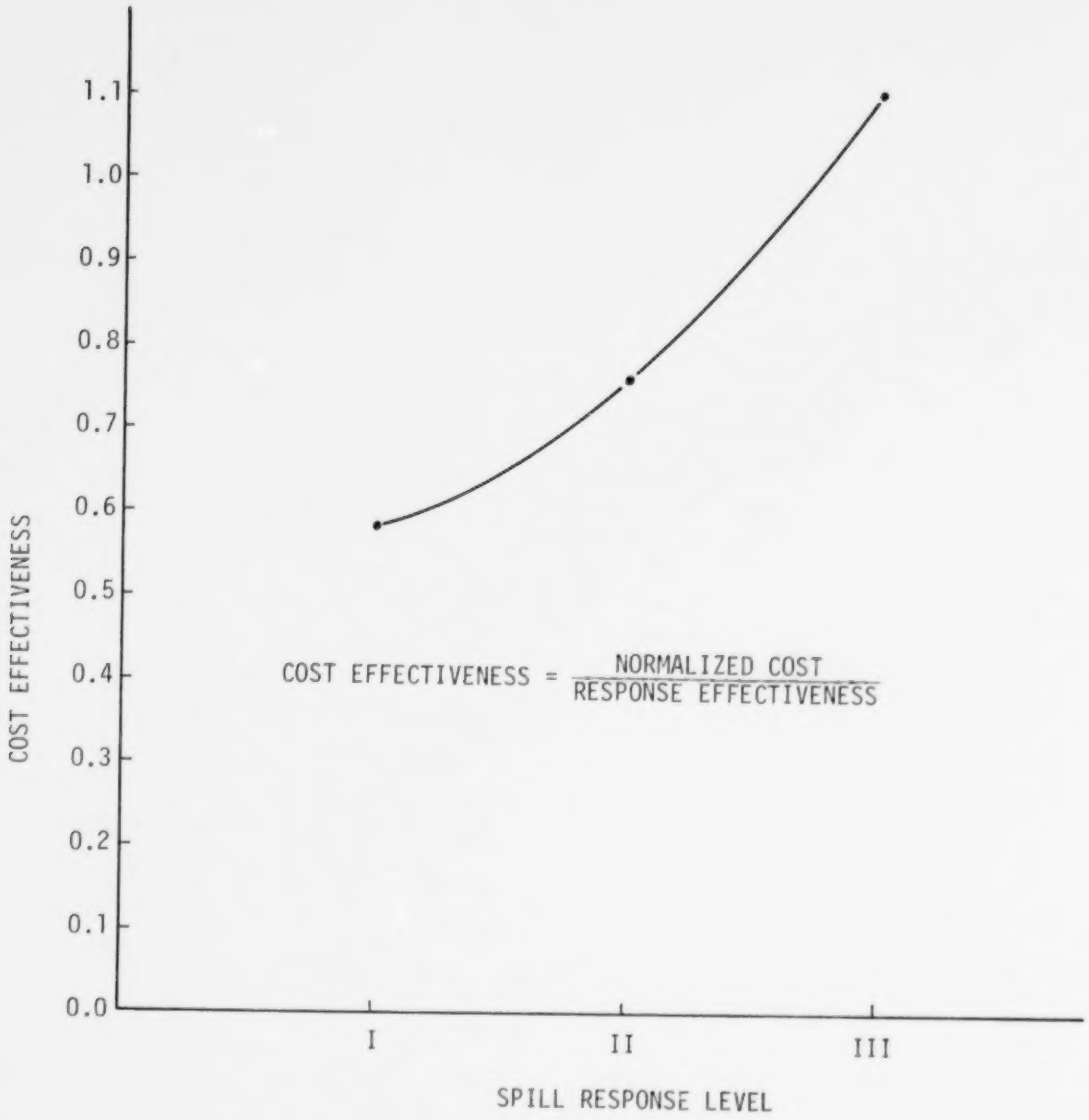

Figure 62. Tank truck spill cost effectiveness vs spill response level.

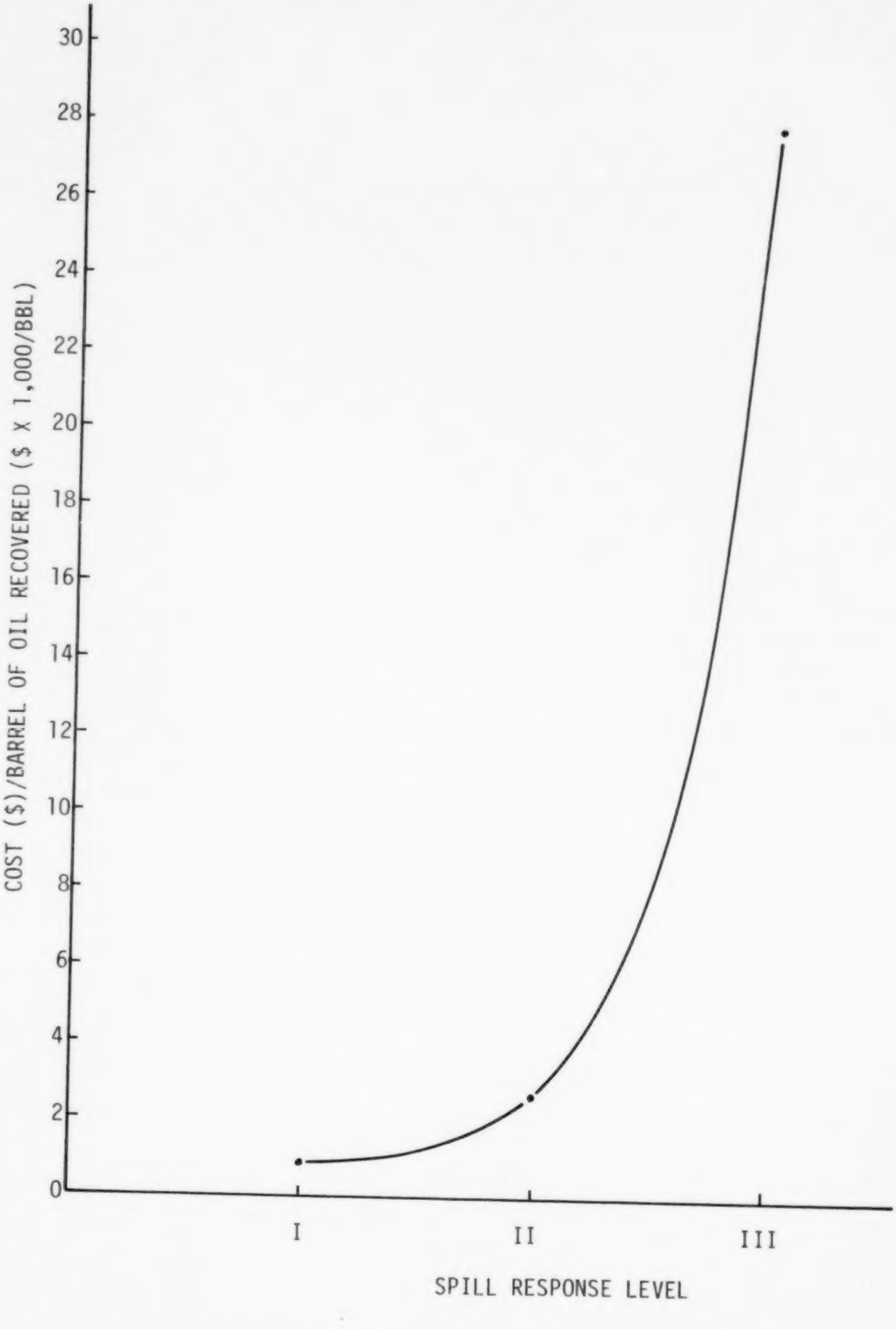

Figure 63. Tank truck spill cost/barrel of oil recovered vs spill response level.

Summary of the Tank Truck Spill Effectiveness Analysis

The analysis shows that the minimum acceptable level of spill response is the most cost effective. Higher levels of response collect only a small amount of the spill, and therefore are not cost effective. A major problem in improving performance in the scenario is that a large part of the spill is not available for recovery. This is the part of the spill that enters the stream before effective response action can be taken. The impact of this part of the spill on the stream is high, and remains high even though most of this product evaporates and is gone before it can be recovered. This result emphasizes the need for controlling a spill before it reaches a highly sensitive stream.

R&D INITIATIVES SUGGESTED BY THE TANK TRUCK SPILL SCENARIO

Response Level I

Many observers believe that burning a spill on the ground is the best course of action to take in some spill situations. The likely success of this action depends on the size and type of the spill, the location, the ground type, the type of vegetation that occurs, the season, and the amount of moisture present in the ground. Burning is more likely to be successful if it occurs before the oil has weathered. In addition, making a decision to burn promptly may prevent the oil from moving into a more sensitive area.

Since so many variables are involved in making a decision to burn, it appears that an R&D project should be initiated to help responsible officials in the field to make this decision quickly and accurately. It appears that some basic research is required to determine the impact of burning in a wide variety of conditions. Disagreements over the advisability of burning seem to be the result of a lack of data. Tests should be performed to identify the conditions in which burning does appear to be the best alternative. Since it seems likely that tests could not cover all possible sets of conditions, a decision aide should be developed to assist officials in the field in quickly assessing local conditions to determine if burning should be used as a method of response.

Response Levels II and III

No additional R&D initiatives are proposed.

SECTION 10

RECOMMENDED RESEARCH AND DEVELOPMENT INITIATIVES

The section describing spill response methods for each scenario concludes with a discussion of possible spill response R&D initiatives for each response level. This section draws these recommendations together and establishes a set of priorities. The priorities are intended to show the order in which the projects should be considered, or put another way, the level of urgency that should be attached to each project. This order, or course, cannot be exact, but it is arranged in a way that is likely to satisfy the requirement to have the most urgent categories of tasks grouped together and in the right order.

To develop the pattern of priorities, the list begins with the most urgent spill response tasks, containment and recovery. Since a number of recommended R&D tasks involve containment and recovery, the list begins with the containment and recovery requirements that are likely to occur most frequently in remote inland environments. R&D initiatives associated with less urgent response functions follow. These include spill disposal, surveillance, and site restoration.

A total of eleven R&D initiatives were recommended in the response method descriptions. Of these, two are similar, cleaning gravel and cleaning sand, and therefore these are combined. Another project was considered to be minor and was eliminated. This leaves a total of nine possible R&D tasks which are described in the paragraphs that follow.

R&D INITIATIVES SUGGESTED BY SPILL SCENARIOS

Cleaning Oiled Snow

Cleaning or processing oiled snow is a routine operation in Alaska, but there appears to be no standard, easy way of doing it. In the blowout scenario, cleaning is performed by melting the snow in an air berm and skimming the oil off the top of the water. Although this procedure is effective, it is relatively slow and labor intensive, and therefore expensive. A single device is needed that performs all of the steps of the process that are presently performed by the response crew at the air berm. For example, the device might have a hopper where the oiled snow could be loaded and then transported to a section that separates the snow and oil by melting, or some other means. The water and oil would then be separated and the oil could be put in temporary storage or disposed of directly with another device such as a portable open flame burner. Oiled snow is found in a great many Alaskan inland spill situations. In fact, snow is often used as a sorbent in the winter. This use of a readily available, inexpensive product for spill recovery could be enhanced by having a device that could quickly extract the oil on site.

Cleaning Sand and Gravel

This requirement occurs in two of the scenarios in this study and therefore the requirement has been combined. First, in the blowout scenario there is a requirement to clean the oiled gravel from the drill pad. This is accomplished by steaming the gravel in a steel basket in a snow melter. In the pipeline scenario, large areas of the surface of the shoreline are removed for disposal. In the first case, the response method is probably satisfactory environmentally, but it is not efficient. In the second case, removal of the top surface of the shoreline is both inefficient and damaging to the environment. A device or method, is needed to efficiently clean the oiled sand and gravel and leave it in place with a minimum amount of damage to the environment. The required device might be a portable, diesel fired burner that could be used to clean the sand on site. The problem of cleaning an oiled shoreline occurs in so many cases that this should be a top priority R&D project.

On Site Burning

Many observers believe that disposal by burning the spilled product in place is a good method of response in some cases. The problem is to identify the cases in which this method is the best one available. Burning with little permanent damage to the environment is possible in certain seasons of the year, with certain kinds of vegetation, terrain conditions, and moisture. Additional information is needed to establish the criteria for determining when burning is the best course of action. It is therefore recommended that a basic research program be initiated to determine the impact of burning in a wide variety of conditions. These tests should be directed toward developing a set of decision-making criteria for use in the field. To be effective, the decision to burn must be made quickly, and should be based on a good understanding of the environmental conditions in the area and the possible impact that could result from the on-site burning.

Fast Current Containment Booms

The swift, debris laden rivers of Alaska make the deployment of containment booms a problem. In many cases it would be desirable to use containment booms, but they are not used because existing booms are not effective in these conditions. The following program is recommended to correct this problem:

- Test existing booms to determine which are the best suited for use in high current, shallow stream situations
- Use a hydraulic model to determine the best ways to deploy booms in these situations
- If none of the booms available are suitable for this application, design a new boom.

Fast Current Recovery Device

When oil is successfully retained behind a boom in a swift river in Alaska, there remains the problem of recovering the slick. The ideal device would be effective in recovering a thin slick in a fast current. Although many recovery devices are available, many do not meet the requirements of portability and ruggedness. More importantly, light weight devices that can be deployed in remote areas are not effective in recovering a thin slick. It is therefore important that tests be performed to determine if any existing devices meet these requirements. If a suitable skimmer is not identified, a new device should be developed.

Portable Flaring Burner

Disposal of the recovered product is frequently a problem in Alaska. In remote inland areas, most of the standard methods of disposal are not possible. Further, transporting the recovered product out to a site where some method of clean disposal is possible is also a problem. It would therefore be useful to have a portable device that could be used to provide an environmentally safe method of disposal in remote inland areas. To meet this requirement, it is proposed that a portable open flame burner be developed that could be transported to remote areas and used to provide a safe, clean burn of the recovered products. Having such a device would eliminate many of the problems associated with the transport of recovered product for disposal. In addition, on-site disposal would help to protect the environment because there would not be a requirement for heavy vehicles at off-the-road spill sites.

Surface Detection of Product on the Water Table

In the fuel farm scenario, the area of the spill on the water table cannot be determined from the surface. The only way to map the area of the spill is to drill holes in the ground until spill locations are discovered. This method is slow, expensive, and destructive to the terrain. It would therefore be useful to have a device that could sense the presence of underground oil from the surface. It is recommended that a device capable of detecting oil on the water table from the surface be identified or developed.

Site Restoration

There is wide disagreement about the kinds of actions that should be taken for site restoration. In order to provide the basis for making decisions concerning site restoration, a research project should be initiated to determine the best ways of responding to some of the following situations:

- Oiled beaches and shorelines
- Oiled debris and vegetation
- Oiled wetlands
- Oiled soils.

Decisions concerning the action to take for site restoration must be made on a case-by-case basis; however, it appears that there are no generally accepted criteria for making these decisions. It is therefore recommended that a research project be initiated to identify and describe acceptable methods for site restoration. These methods should be accepted and approved by the responsible State and Federal authorities in Alaska. The accepted methods of site restoration could then be used for on-site decision making by spill response crews.

Identifying Cost Effective Levels of Spill Response

The cost effectiveness analysis of each of the scenarios in this study shows that the final intensive effort to recover the last small amount of oil is not cost effective. In some cases, this effort may be more damaging to the environment than leaving the oil in place. To correct this situation, a judgment must be made before taking action to remove the final traces of the spill. The problem is that there are no criteria available for making this decision.

It is therefore proposed that the needed decision criteria be developed based on a data base that shows the expected result of spill response actions in various situations. This data base would include the results of actual spill situations plus the analyzed results of spill simulation modeling. The actual situations could be developed into a practical decision file that shows the spill response results in real situations. These records would be supplemented with computer simulations of typical spill response problems with results presented in the form of a cost effectiveness analysis such as the one performed in this study. These results, combined with the actual spill records, would be used to establish a set of decision making criteria to be used by responsible officials directing spill response operations. The data would provide them with the basis for making a judgment concerning the likely effects of the final, intensive spill response effort.

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APPENDIX

OIL SPILL SENSITIVITY FACTORS

RATING CRITERIA BASED ON A SCALE OF 0-4

PHYSICAL FACTORS

Soil Stability

The characteristics of a soil which determine its resistance to such changes as erosion, slumping or other failure.

0 - No measurable effect

1 - Slight change in stability

2 - Moderate change in stability

3 - Severe change in stability

4 - Extreme to complete change in stability; soil will slump or erode readily without further stimulus

Permafrost

Any surficial deposit or bedrock that remains at a temperature below 0°C for two years or more.

0 - No measurable effect

1 - Slight degradation of permafrost

2 - Moderate degradation of permafrost

3 - Severe degradation of permafrost

4 - Complete degradation of permafrost

BIOLOGICAL FACTORS

Aquatic Habitats (Fresh)

Lake and river systems, including their physical and chemical features and biological productivity.

(Continued)

0 - No measurable change

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Complete change in the physical or chemical characteristics that eliminates biological productivity.

Wetland Habitats

Lands that are temporarily or seasonally covered by shallow standing fresh or brackish water.

0 - No measurable change

1 - Slight adverse effect on productivity of the habitat

2 - Moderate adverse effect on productivity of the habitat

3 - Severe adverse effect on productivity of the habitat

4 - Changes in physical or chemical characteristics that completely eliminate biological productivity

Upland Habitats (Unvegetated)

Lands that are not covered by standing water and do not support extensive vegetation.

0 - No measurable change

1 - Slight adverse effect on capability of the habitat to support the organisms that normally use it

2 - Moderate adverse effect on capability of the habitat to support the organisms that normally use it

3 - Severe adverse effect on capability of the habitat to support the organisms that normally use it

4 - Completely destroys the capability of the habitat to support the organisms that normally use it. For example, cliff nesting sites are rendered unsuitable for nesting.

(Continued)

Upland Habitats (Vegetated)

Lands that are not covered by standing water and do support extensive vegetation cover.

0 - No measurable effect

1 - Slight adverse effect on productivity of the habitat

2 - Moderate adverse effect on productivity of the habitat

3 - Severe adverse effect on productivity of the habitat

4 - Complete change in physical or chemical characteristics that eliminates biological productivity.

Finfish

All species of bony or cartilaginous fishes.

0 - No measurable effect

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Complete elimination of finfish from the spill area

Birds (Water-Related)

Birds that habitually live on or near water at the time of the spill. This would include, for example, eagles in salmon habitats during the period of salmon runs, as well as waterfowls, loons, grebes, shorebirds, and others.

0 - No measurable change

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Total mortality of all water-related birds present.

(Continued)

Birds (Non-Water-Related)

Birds that do not habitually occur on or near the water at the time of the spill.

0 - No measurable change

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Total mortality of all non-water-related birds present.

Mammals (Water-Related)

Mammals that habitually occur on, in, or near fresh or brackish water at the time of the spill. Examples would be muskrat, beaver, and during fly season, moose.

0 - No measurable change

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Complete mortality of all water-related mammals present.

Mammals (Non-Water-Related)

Mammals that do not habitually occur in, on, or near water at the time of the spill.

0 - No measurable change

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Total mortality of all non-water-related mammals.

(Continued)

BIOPHYSICAL

Wilderness

The land, its waters, air, vegetation, and wildlife unaffected by the works of man. Human perceptions are not included here.

0 - No measurable effect

1 - Slight modification of the natural condition, an alteration in a small portion of the area, or a temporary alteration (as oil in a river that is soon dispersed).

2 - Moderate modification of the natural condition

3 - Severe modification of the natural condition

4 - Extreme alteration of the natural condition.

HUMAN FACTORS

Human Use of Minerals

The extraction and storage of minerals from the land or water. This would include hard rock and placer mining, as well as mining of sand and gravel.

0 - No measurable change

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Total impairment of the mineral extraction activity.

Human Domestic Use of Water

This would include collection, storage, and use of water for domestic and culinary purposes. It would not include industrial use or use for navigation or swimming.

0 - No measurable effects

1 - Tainted, but otherwise safe for human consumption

2 - Safe for human consumption only after treatment

(Continued)

3 - Unsafe for drinking, but suitable for washing after treatment

4 - Water rendered totally unfit for any domestic use.

Human Use of Vegetation

The gathering, storage, and use of vegetation such as berries and roots for human consumption, grass for baskets, and firewood. This excludes agricultural uses.

0 - No measurable effects

1 - Tainted but still safe for human consumption

2 - Unfit for human consumption, but suitable for manufactured goods

3 - Usable only as fuel or for rough construction

4 - Vegetation rendered unfit for any use

Human Use of Fish

The gathering, storage, and use of fish, including shellfish or finfish, whether commercial, subsistence, or sport.

0 - No measurable effect

1 - Tainted, but safe for use

2 - Unfit for human consumption, but suitable for dog food

3 - Unfit for animal consumption, but suitable for some industrial uses

4 - Renders organisms entirely unfit for any use

Human Use of Birds

The taking, storage, and use of birds.

0 - No measurable effect

1 - Tainted but safe for human consumption

2 - Unfit for human consumption, but suitable for such uses as crafts, and clothing, etc.

3 - Suitable for limited uses

4 - Renders the organism entirely unfit for any use

(Continued)

Human Use of Mammals

The taking, storage, and use of mammals.

0 - No measurable effect

1 - Value of a single use of a major species diminished

2 - Value of more than one use of a major species diminished, but most uses unaffected.

3 - Value of most uses of mammals diminished

4 - Renders totally unfit for human use one or more species within the area of the spill that are of major importance to residents that use the area.

Other Community Activities and/or Facilities

Conducting business, swimming, recreation, religious observances, social functions, education, and maintenance of non-agricultural livestock.

0 - No measurable effect

1 - Creates a slight difficulty or impairment of an activity important to the area

2 - Moderate difficulty or impairment

3 - Severe difficulty or impairment

4 - Renders any such other activity important to the area impossible to pursue.

Endangered Species

Individuals or habitats of species that have been designated as endangered under the terms of the Endangered Species Act of 1973.

0 - No measurable effect

1 - Slight adverse effect on individuals or significant habitat

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Destruction of an individual or significant critical habitat

(Continued)

Aesthetic Quality

A value that derives from individual perception of beauty in an object, activity, or scene.

0 - No discernible effect

1 - Slight adverse effect

2 - Moderate adverse effect

3 - Severe adverse effect

4 - Renders the object, activity, or scene totally repugnant.

Specially Designated Areas

Areas legally or socially designated by man as having special significance.

0 - No measurable effect

1 - Slight diminution of the value for which the site was designated

2 - Moderate diminution of the value

3 - Severe diminution of the value

4 - Complete destruction of the value for which the area was designated.

Air Quality

0 - No measurable effect

1 - Slight unpleasant odor

2 - Unpleasant odor, some impairment of activity

3 - Health hazard

4 - Potentially lethal effects.